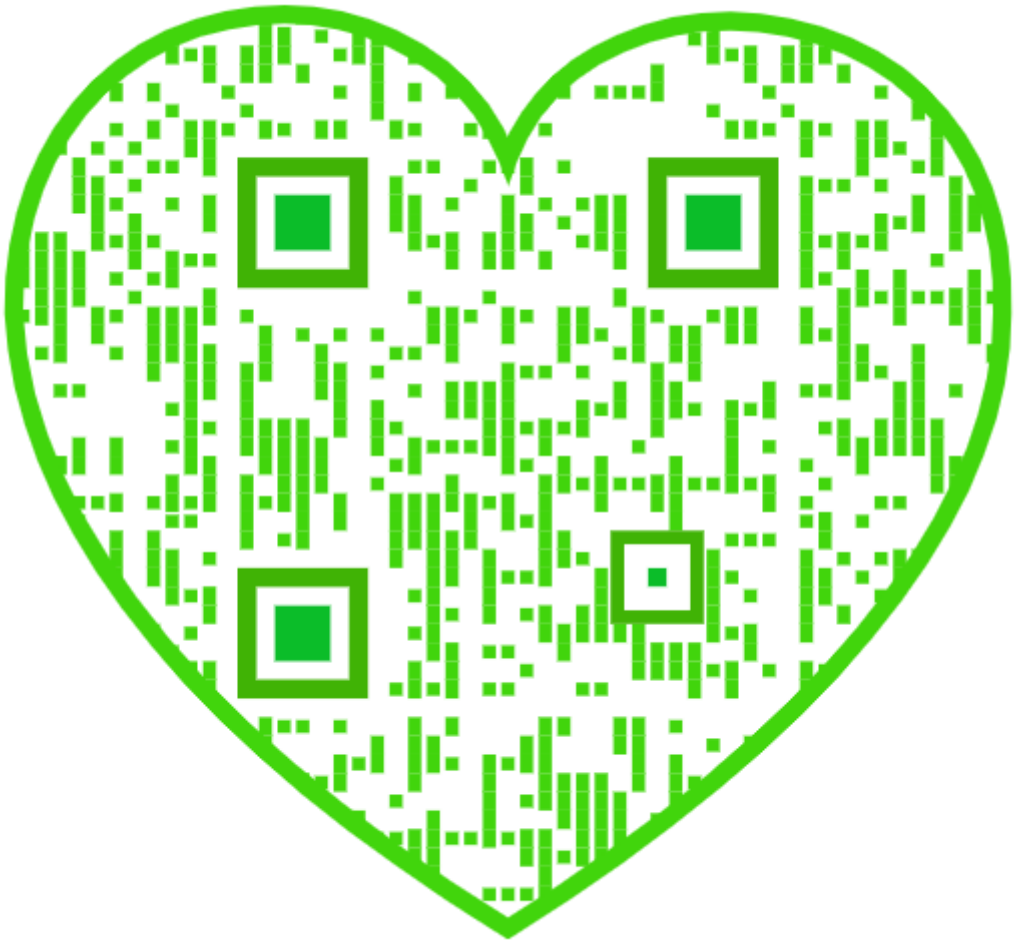
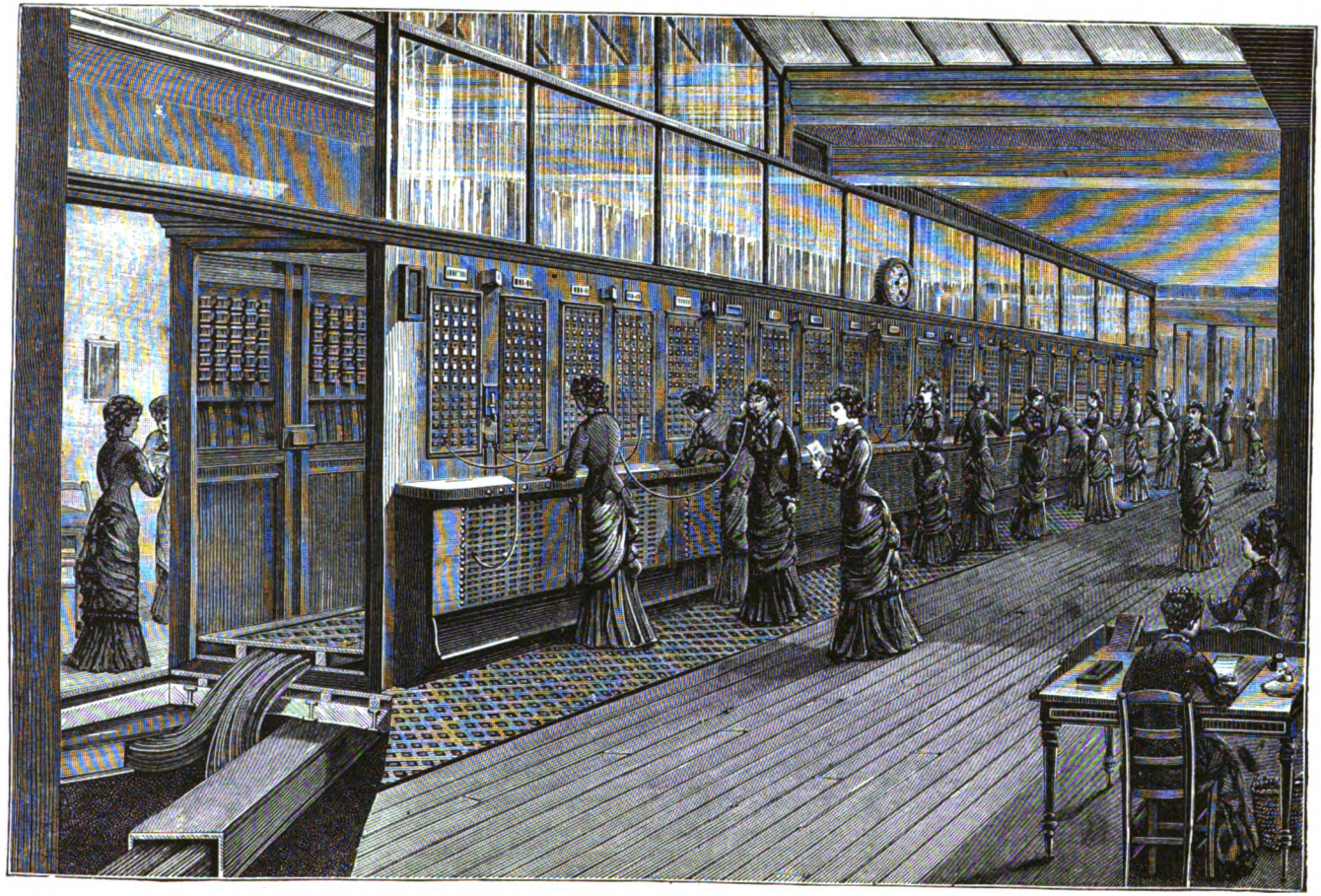


ELECTRICITY

IN THE SERVICE OF MAN.



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ELECTRICITY

IN THE SERVICE OF MAN:

A Popular and Practical Treatise on the Applications of Electricity in Modern Life.

From the German of Dr. Alfred Ritter von Urbanitzky.

Edited, with Copious Additions,

BY

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With an Introduction by

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CONCLUSION.

PREFACE.

THE German Author, in his brief Preface to the original work upon which the present treatise is based, thus describes his purpose :—

"In its power to assume always that form of energy which happens to be the most useful, lies the great importance of Electricity. This importance has been brought home to the public at large by means of the many recent exhibitions. Public interest has been roused, and there is everywhere a desire for information, and a demand for a guide through this mysterious and far-extended territory. Although there is no want at present of works and periodicals which treat of the science of electricity, it is not everybody's business to go through fifty volumes to pick out from amongst the useful and useless that which is needed, and finally to retain just enough to make up one volume.

"The task of saving the general reader that trouble I have undertaken, and have sought to convey a clear insight into the whole science of modern electro-technics, without requiring on the reader's part any special knowledge beyond that of ordinary education. The very complete index is further intended to make the work of use as a book of reference."

In the preparation of this English Edition, we have sought to preserve all the many excellent features that make Dr. Urbanitzky's work so admirably adapted for a popular and practical treatise. We have not hesitated, however, to alter the method with great freedom where it was out of accord with English modes of thought or reasoning, and to add descriptions of apparatus made and used in this country, and matters generally interesting to English readers, which were not found in the German edition.

In the main divisions of the subject we have, to a great extent, followed the original. The best order for elucidating the principles of

this and kindred sciences is, as a rule, the historical order of discovery. The facts that are first found in order of time are those that are most palpable and lie nearest to hand; while, on the other hand, the discoveries of recent years are drawn from the more intricate phenomena, which require to be searched after. But the order of development is thus almost exactly the reverse of the order of importance and utility, as regards the purposes of life; nor is the order of discovery strictly identical with a logical arrangement. Dr. Urbanitzky has taken account of this difference, by first expounding the Principles of Electrical Science in their historical sequence, in the first part of the work, and then dealing with the applications of electricity to industrial life, in a second part. Moreover, the same plan is used in dealing with the separate branches of the subject, as is applied to the work as a whole; and hence in each of the sections on Dynamos, Motors, Accumulators, Telephones, Telegraphs, etc., the historical sketch of the progress of discovery precedes the general examination of the subject.

This plan appeared so judicious that we have followed it out fully, though we have endeavoured to simplify the second part by a rearrangement of some of the sections. In one respect, however, we have not followed the German. The biographies of discoverers and inventors, with their portraits, seemed unduly to dilute the strictly scientific record; and with some reluctance, therefore, these interesting personal details have been omitted.

Although the systematic exposition of the science, as a whole, is to be found in the first part, a sufficient explanation of the principles is given in each section to make the applications intelligible to the readers who are particularly interested in the one branch of the subject treated of in that section, and who, therefore, consult the work for that particular branch.

To facilitate reference, an account of the units of electric measurements, and the principal laws connecting them, are collected in an Appendix to Part I.

Dr. Urbanitzky makes considerable use of the analogy between a flow of water and a flow of electricity, for rendering easier the comprehension of the meanings of terms, and the retention by the memory of the relation between the different electrical quantities. This analogy has been made use of in the following cases:—

Page 43.—The analogy between potential and level.
116.—The pressure of water and the E. M. F. of electricity.
124.—The law of divided currents and the theory of Wheatstone's Bridge.
248.—The action of a Gramme collector and the union of a double flow of water.
353.—A small quantity of water with a high fall feeding a number of water-mills at different levels, compared with a system of machines in series; and a small fall of a large quantity of water feeding machines at the same level, compared with a system of machines abreast.

It has been urged that the analogy may be carried too far, and, in particular, that the flow of water through a pipe, unlike the flow of electricity through a wire, has no effect on the region outside. To this objection we might reply that analogies are never intended as proofs, but as illustrations. No analogy is perfect; a perfect analogy would become an identity. Although the analogy between two sets of phenomena may be traced to a great length—

> "Though each resemble each in every part,
> A difference strikes at length the musing heart,"

and the detection of the diversity amidst general resemblances, may be of as much advantage to the student as the recognition of the resemblances. But it is by no means clear that we have exhausted the analogy in the case before us. For instance, although water flowing through a closed pipe has no field of influence outside the pipe, if we substitute a stream for the closed conduit, the analogy continues—

> "Streams never flow in vain where streams abound,
> How laughs the land with various plenty crowned."

The stream must be drawn upon, however, in order that its influence may be utilised, and so also must the current. Whenever the influence of the field surrounding any part of the circuit is taken advantage of for

mechanical or other work, a counter electro-motive force is produced which is equivalent to a reduction of the difference of level.

We have next to notice the points in which we have not followed the original. The Author's anxiety to avoid the appearance of a mathematical work, which might make the subject repulsive to many, has led him to avoid all symbolic statements whatever. But frequently the symbolic form is the simplest and most intelligible expression of a relation, and is far more readily comprehended by the general reader than a lengthy expression in words. Hence we have followed up the verbal statement of laws by repeating the statement in the symbolic or equational form. By this plan we have not forfeited anything of the popular character of the work, but we have at the same time caused the popular introduction to lead up to the more scientific or technical treatment in every branch of the subject as it occurs. Again, whenever the laws which were simply enunciated in the original, admit of simple demonstrations, we have given the proofs; and, in the case of dynamo-machines and motors, we have extended the "plotting-out" methods which are briefly mentioned by Dr. Urbanitzky, and made these methods the means of explaining the theories of Marcel Deprez, Dr. Fröhlich, and Dr. Sylvanus Thompson.

Again, we have made less use than the original of the theory of Symmer and Du Fay, namely, that there are two kinds of electricity, and that a current consists of a double flow—a flow of positive electricity in one direction, and a flow of negative electricity in the other or opposite direction. This theory is fully explained in its historical connection, but we have speedily replaced it by the modern forms of speech, which do not pledge us to *any* assumption as to the nature of electricity. The only assumption we make is that, whatever electricity may be, one body may have more or less of it than another, and that as compared with a standard body, such as the earth, one body may have an excess and another a defect. Though there are not two kinds of *electricity*, there are two kinds of *electrification;* one being a state in which there is more electricity than on an equal surface of surrounding bodies, and the other kind a state in which there is less. To follow out the older theory would require that the unit of current should be half that which is now universally adopted, and of the other units, some should be doubled or quadrupled, and others should be halved or quartered. According,

therefore, to the view we have adopted, all electrical machines or batteries are but instruments for altering the distribution of electricity. Any cause which is sufficient to alter the distribution of electricity produces an electro-motive force, or potential difference, and no charge of electricity whatever can be made sensible without some difference of potential between the charged body and the earth or neighbouring conductors. Friction between non-conducting bodies gives rise to a great potential difference, producing a large charge on even a small conductor; whereas the galvanic cell or the contact of conductors produces a very small potential difference, giving a small charge only to any conductor of moderate size. On the other hand, when the conductor is large the galvanic cell will develop a large quantity of electricity, and the friction machine only a small quantity.

The practical system of electrical units—the *ampere*, the *volt*, and the *ohm*—have been used throughout, and their connection with the so-called absolute units is traced in the Appendix to Part I.

The explanations of the phenomena of magneto-electric induction are given by means of Faraday's law and Maxwell's rule—that is to say, by the conception of lines of force.

To emphasise the principal objects of the work, an Introduction by Professor John Perry reviews the following essential characteristics:—

1. The method of following up analogies as far as possible. To this we have already referred.

2. The advisability of keeping in view the older methods and instruments, so as not to allow recent discoveries to cause them to be regarded as useless. Instruments that have been for a time regarded merely as toys, may suddenly be brought into demand for practical purposes, and ought not to be lost sight of. It is becoming the fashion, for instance, to look upon frictional or statical electric machines as things of the past; but there are several discoveries of late years which seem to hint that they may yet be utilised to a greater extent than hitherto. As an example, Professor Lodge has shown that dust and vapour suspended in the air can be "settled" by an electric discharge, consisting of a continuous series of electric sparks. This fact, when once stated, has speedily been applied to clear the atmosphere in lead-smelting works from the fumes of volatilised lead. Almost contemporaneously with this discovery, comes the invention of the ingenious influence machine of

Wimshurst, which produces with a minimum of difficulty and mechanical labour, a continuous series of such sparks, and appears admirably adapted for any purpose—of which more may possibly be discovered—requiring the simple production of electric discharges through the air.

3. The third point entered into more fully in the Introduction, is the advantage to the cause of discovery of the general diffusion of a knowledge of the chief electric phenomena through the community. The applications of electro-technical science in regard to illumination, the transmission of power, intercommunication, etc., are before all eyes, and there is a pressing desire to know more about them, not only on the part of the professional public, but also on the part of educated and intelligent people generally.

Our aim has been to supply that information in a form suitable for the general inquirer, and yet to connect with it detailed and definite facts and figures which may be of service to technical students and professional workmen.

We have only to state in conclusion, that the draft translation of the original work (which has received, however, very free handling, for reasons already indicated) has been executed by Mr. Emil Beyer. And we have also to thank the numerous electrical engineers or inventors who have rendered valuable aid in bringing the work up to date, by supplying information (often accompanied by illustrations) and revising the proof-sheets of the text. Amongst these we are particularly indebted to Messrs. Ayrton and Perry, Mr. James Wimshurst, Mr. Alexander Schanschieff, the Brush Company, the Exchange Telegraph Company, and Messrs. Siemens, Edison & Co., Gerard & Co., Higgins, and Fuller.

INTRODUCTION.

THE history of electrical engineering differs from that of any other application of the principles of natural philosophy in this important respect, that long after practical men had developed elaborate mathematical investigations, the results of which were absolutely necessary to them, nearly all the teachers of the science of electricity in colleges and schools remained in a state of ignorance of everything except what may be called a list of electrical tricks. We may say that, up to as late as about 1870, there were really no text-books on the science of electricity. There were, indeed, publications in which the speculations of Franklin and other writers of from seventy to one hundred years ago, on the nature of electricity, were fully entered into. Careful descriptions were given of rubbed glass-plate machines, of batteries of Leyden jars, the giving of shocks, the production of scenic effects by electric sparks, and the use of glass-legged stools. In general, such information was given as might be found useful by practical jokers. The information on magnetism was of much the same childish order. The department of voltaic electricity or galvanism, as it was called, consisted of descriptions of various forms of voltaic cells, and of methods of joining cells together, so as to produce a maximum current in a circuit, with perhaps a description of the single-needle telegraph. The book was usually redeemed from worthlessness by some account being given of Faraday's experiments; but readers found that the main outcome of Faraday's work was the Ruhmkorff induction coil, whose important function was to illuminate Geissler's tubes for children's parties.

That electricity from a rubbed glass machine had anything in common with voltaic electricity; that calculations might be made concerning electric phenomena; that, in fact, there was a science of electricity as distinguished from a mere natural history;—such facts as these were almost unknown to the writers of text-books and teachers. The researches of Cavendish, of Faraday, and of Joule were known to a few; Thomson's magnificent series of papers had been published, some of them more than twenty years; in fact, the science of electricity, as we know it now, had really been developed. But it was buried in *The Cambridge and Dublin Mathematical Journal*, *The Philosophical Magazine*, and the transactions of a number of learned societies. A knowledge of the meaning of electric potential might be arrived at in a roundabout way by a student of the higher mathematics who approached it from the astronomical side, but

only a few men, besides Sir William Thomson himself, saw any connection between mathematical investigations on the subject of potential and ordinary electric phenomena. It was a weary time for young students. We knew that there was some connection; we knew that Thomson was really able to make calculations of a useful kind in his practical work on submarine cables, but there was no text-book and there was no teaching. Even those who were so privileged as to come in contact with Thomson during this dark interval, had a feeling of ignorance when he spoke of potential, as we now speak of it; a hopeless feeling that it was impossible to grasp the connection between our mathematical work and ordinary electric phenomena. Yet poor as the help might be which was afforded to English students of electrical science, they were highly favoured mortals in comparison with students in France, where even the results of Faraday's experiments were unappreciated.

At length, in 1870, Dr. Everett wedded notions of potential to the detached experimental information of a French treatise on electricity, which he translated; and the books of Fleeming Jenkin and Clerk Maxwell, published soon afterwards, completely removed all impediments in the way of electrical students. The full meaning of Ohm's law became clear; electro-motive force, difference of potential, resistance, current, capacity, lines of force, magnetisation, chemical affinity, were measurable, and could be reasoned about, and calculations could be made about them with as much certainty as calculations in dynamics. Information was now published which had long been known to the practical electrical engineer, but which had been really unknown to the writers of text-books and the teachers of science. It may be said that from 1870 the teaching of electricity has ceased to be a mere lecture-room exhibition of tricks and startling electrical effects, and has become a more and more widely known science. But it is only since about that time; and while it is useless to speculate on what might have occurred had Sir William Thomson condescended to write in 1857 a text-book on electricity such as he was then capable of producing, it may safely be said that it is very seldom that a man's inability to comprehend how ignorant his contemporaries are, has produced such evil effects in retarding the progress of industrial invention.

But now that we have at last a science of electricity, and that the applications of the principles of this science are proceeding so rapidly in the invention of new machines, we are apt to neglect a part of the subject which was certainly not neglected twenty years ago, namely, the historical part. We are apt to forget the names of the men whose discoveries have been welded together by Thomson and Maxwell; to forget that Pliny described the electrical properties of amber; that the Chinese were acquainted with the directive property of a magnet long before the adventurers who discovered Iceland (described by Snorro Thurlesson); that gradually from these early times our knowledge of the subject has been getting greater and greater, and that if at any time the knowledge of a few had been published more freely, we should now be much more advanced than we are. It hardly seems possible to us, now-a-days, to

imagine that the acute thinkers of Greece lived with exactly the same sort of phenomena occurring around them, as occur around us now; that the lightning-flash taught them nothing of electrical phenomena; that they knew nothing of the earth currents which are continually flowing; and that they never happened to transmit speech in any of the many simple ways by which we find that it may be transmitted now.

There can be no doubt that the people of one hundred years hence will wonder in the same way, that we shall have remained so oblivious of phenomena occurring around us, to which they will not be able to shut their eyes. Of all the many wonderful but simple inventions which they will make themselves, and which are unknown to us, the discovery of a single one at the present time would be a great event. They will probably speak to one another at a distance without any artificial connection between. They will probably be able to see one another's actions at great distances, just as if they were close together. Many of the phenomena hinted at in Eastern stories, and now regarded by us as fabulous, will be happening, and will not be thought extraordinary; and the *vril-staff* will have already become familiar to the hands of man. To hasten such discoveries ought to be the aim of everybody; for the social changes produced by the agency of the steam-engine in factories, in ships, and in railways, and by the agency of other applications of scientific principles, are too great to be put in comparison with those produced in the history of man by any other agencies.

However, it is not only by the study of the few, but also by the intelligent observation of the many, that discoveries are brought about. We must give to every unit of the population the chance of becoming a Watt or a Faraday. It is by the spread of education among the masses of the people, that we are hastening the discovery of new civilising agents. The history of electrical engineering during the last fifteen years is one of the best illustrations that can be given of the fact, that for many people to have some knowledge, however low in level it may be, is as necessary to the development of discovery as for a few people to have knowledge, however high in level. Very slow and difficult has the progress been since the beginning of this century, when the electric arc was discovered; since Faraday's discovery of electro-magnetic induction, which is the principle of all dynamo-electric machines; since Grove invented his gas battery, Ritter his secondary piles, and Planté the germ of the modern accumulator. But between 1860 and 1870, mainly, I believe, in consequence of the work done by the Science and Art Department, a working knowledge of the principles of the science which until then had only been known to a few people became the property of thousands of mechanics, and it may almost be said that the rate of progress in electrical discovery became proportional to the number of people who had some electrical knowledge. The small magneto-electric machine, regarded as a toy for giving shocks, led to the machine invented by Wilde, in 1866, in which excited electro-magnets were employed. In that year Varley and others made independently one of the

grandest discoveries of the century, and presently a machine was in use which excited its own field magnets, the type of all dynamo-machines since that time. With this principle of Varley's, and using the form of armature employed by Pacinotti in 1860, Gramme invented, in 1871, his famous continuous current generator, which has revealed to the world how much electrical power is obtainable from a small machine.

The world has seldom seen such a period of scientific unrest as occurred (mainly in this country and in America) from 1878 to 1883; but amidst the multitude of discoveries and inventions which are the products of that restless period, there are, I repeat it, few which were made by the mathematical leaders. Most of them may be regarded as the results of the demand which the workmen had already begun to make for a clear knowledge of the principles which underlie their operations. There were thousands of workmen who were continually asking for advice, or for more knowledge of what was already known to the few; and the few aroused themselves, and put their knowledge in simpler and more exact forms before the world; still discoveries and inventions were made not by the learned few, but by the fortunate few of the unlearned many. We had the Gramme and Siemens dynamo-machines followed rapidly by a hundred others, so much alike in principle, that when one is clearly understood the principle of another is known after a very short examination. What was wanted for the proper working of an arc electric light became known to the many; and in a short time hundreds of interesting methods of regulating the electric light were abroad. That a filament of carbon in a state of incandescence from the passage of an electric current could be used as a lamp, had been known to the few for many years; but immediately after this fact became generally known hundreds of incandescent lamps were invented. In this treatise we are introduced to the names of the discoverers in electrical science, their discoveries and inventions of machines and instruments are described, and an attempt is made to explain the action of these machines and instruments through electrical principles.

It is, however, to be observed that in attempting to put electric principles before the general reader, the fact that these principles are essentially of a mathematical character cannot be ignored. It is true that in applications of electricity, as in applications of mechanics, the student is often able to arrange apparatus with which many curious phenomena may be observed, without his having much knowledge of electrical or mechanical magnitudes; but there can be no doubt that there is an immense waste of time and knowledge due to attempts of this kind. Without a quantitative knowledge of scientific principles, we have students seeking for the elixir of life, the philosopher's stone, and perpetual motion. The old alchemists certainly made discoveries, and the search for perpetual motion has led to great advancements in science, or if to nothing else, to the knowledge that there cannot be perpetual motion. It is also quite true that if Mr. Graham Bell had been well acquainted with Fourier's mathematical analysis, he would have scorned to make the experiments which

led to the discovery of the telephone. We are, however, too much in the habit of forgetting how numerous are the experimenters of this order who discover nothing whatever, and whose time is completely wasted; and it may be laid down as a general rule for electrical students, that he who has not a quantitative knowledge of the principles of electrical science will only waste his time in making original experiments.

I am sorry to say that, even now, the ordinary telegraph operator, and many people who have to deal with electric lighting machinery, are unacquainted with the fact that electricity can be measured. We cannot imagine a mechanical engineer regarding a distance of a few inches as being equal to the distance of a few miles, or even of a few thousand miles; we cannot imagine a grocer to confound an ounce of sugar with a ship's load of the same material; but this gives too truthful an idea of the vagueness, and general want of definiteness, which till a few years ago existed in the minds of nearly all students of this subject, and which even now exists in the minds of a great many practical electricians. Perhaps when electricity is supplied to houses generally for lighting, heating, and driving purposes, at a certain rent per horse-power, and is dealt with by private persons as familiarly as water, this vagueness will finally disappear.

To get exact ideas in any department of physics we have one firm foundation to build upon, namely, that a certain amount of energy, or power of doing work, remains always the same, however it may change its form. We have many sources of electricity: the rubbed plate-glass machine (page 52), the induction machine (page 57), the voltaic cell (page 93), the thermo-pile (page 113), the magneto-electric machine (page 227), the dynamo-electric machine (page 235), and others. To all these some form of energy is given, and they convert this energy, badly or well, into electric energy. To the first two and the last two of those I have mentioned, mechanical energy is given by hand or from a steam-engine, and this mechanical energy is converted partly into heat, which may be regarded as a loss, and partly into the electric energy which we require; but the electric energy is less in amount than the mechanical energy given to the machine. In a voltaic cell zinc is burned; that is, what may be called chemical energy is used up, and electrical energy is given out. In the thermo-pile again, heat energy is given to the pile, part of it being given out as electrical energy.

Suppose that the thermo-pile of Fig. 403 has its terminals connected by a long conducting wire. Now it may be shown in a variety of ways that the wire is not in the same condition as when the pile is disconnected. Thus, it is found that the wire now possesses magnetic properties, and that it is being heated. Without knowing what electricity is, we are in the habit of saying that electricity is passing through the wire, and we think of it in pretty much the same way as we think of water passing along a pipe. However long the wire may be, some electricity will pass through it, so that if part of the circuit is at a distant place, electricity will pass through the wire at that distant place,

heating the wire and making it exhibit magnetic properties.* If an Ammeter, or any other form of galvanometer, forms part of the circuit, the readings of that instrument enable us to measure what we call the quantity of electricity passing. When the circuit is broken at any place and again made, the current is stopped and then flows again. By this we mean that the wire loses its magnetic properties, and ceases to get heat when the circuit is broken, and regains its magnetic properties, and begins to receive heat again when the circuit is made. Again, if the circuit at any place is broken, and the two ends of the wire are connected merely by dilute sulphuric acid, or another electrolyte, it is found that the liquid undergoes chemical decomposition.

Now by any of these three properties of the circuit we can measure what we call the quantity of electricity passing any place per second, or what is called the *current.* When we find that a wire is receiving heat, we know that this heat energy can only have been obtained by an expenditure of some other form of energy somewhere else. When by suddenly making an electric circuit, or breaking it; or by successions of makes and breaks, we cause magnetic needles or magnets, or electro-magnets, to move, we are developing mechanical energy which must have disappeared as another form of energy somewhere else. When we cause the chemical decomposition of an electrolyte, we develop chemical energy which must have disappeared as some other form of energy somewhere else. We give then to the thermo-pile heat, or to another generator we give mechanical energy from a steam-engine, and by means of a metallic circuit connecting the terminals of that machine, which may only be a few yards or may be many miles long, we are able to develop mechanical energy, or heat energy, or chemical energy, at any place in the circuit.

Joule's experiments tell us that any generator gives out exactly as much energy as is given to it, but much appears in the form of heat, so that it is the object of an inventor to construct a generator of electrical energy which shall give out as much as possible of the energy supplied to it in the form of electrical energy. A clear distinction must be made between *electricity* and *electrical energy.* A miller does not merely speak of the quantity of water in his mill-dam; he has also to consider the height through which it can fall. A weight of one thousand pounds, falling through a distance of one foot, represents the same energy, that is, can give out the same amount of work in falling, as one pound through one thousand feet. A mere statement, then, of the quantity of electricity given out by a machine is insufficient; it is also necessary to state what is the height or difference of potential through which it is falling. The quantity of electricity in a thunder-cloud is comparatively small, but the difference of potential through which this quantity passes when discharge occurs is exceedingly great. So it is with the two factors of the electrical energy developed by a glass-plate

* Energy disappears in the thermo-pile and appears at a distant place. But we do not know what has been its direction of flow in the wire; nor whether it may not have flowed in two directions at once. Indeed it seems rather probable that the energy passes through the space outside the wire, and not through the wire itself.

machine. The quantity of electricity obtainable from the machine per second is comparatively small, but it is like a small quantity of water at an exceedingly great height; whereas, in the other machines mentioned, we have, in the analogy of the miller, a very great quantity of water and a very small difference of level.

This water analogy is very useful, because everybody has fairly exact notions about water, and because, within certain limits, the analogy is a true one. The following table gives it more fully:

Water.	*Electricity.*
1. Steam-pump burns coal and lifts water to a high level.	1. Generator burns zinc, or uses mechanical power, and lifts electricity to a higher level or potential.
2. Energy available is, amount of water lifted × difference of level.	2. Energy available is, amount of electricity × difference of potential.
3. If we let all the water flow away through a channel to a lower level without doing work, its energy is all converted into heat because of frictional resistance of the pipe or channel.	3. If we let all the electricity flow through a wire from one screw of our generator to the other without doing work, all the electrical energy is converted into heat because of resistance of the wire.
4. If we let water work a hoist as well as flow through channels, less water flows than before, less power is wasted in friction.	4. If we let our electricity work a machine as well as flow through wires, less flows than before, less power is wasted through the resistance of the wire.
5. However long and narrow may be the channels, water may be brought from any distance, however great, to give out almost all its original energy to a hoist. This requires a great head and small quantity of water.	5. However long and thin the wires may be, electricity may be brought from any distance, however great, to give out almost all its original energy to a machine. This requires a great difference of potentials and a small current.
6. If a pump produces a very slow continuous flow of water in an endless pipe which may or may not work water-pressure engines by its motion, the work done on every pound of water passing through the pump is called the total available *head*, or pressure, and it is greater than the greatest difference of pressure observable between any two points in the circuit.	6. If a generator produces a flow of electricity in a circuit which may or may not work electro-motors, the energy given to every unit quantity (or coulomb) of electricity passing through the generator is called the electro-motive force of the generator, and it is greater than the greatest difference of potential observable between any two points in the circuit.

In fact, if we could leave out of account the kinetic energy, or energy of motion of water, there is the most exact agreement between the laws of pumps, circuits of pipes, and water-pressure engines, and the laws of electric generators, electric circuits, and electro-motors. It will be readily understood that for some purposes it is necessary to have our electrical energy in the shape of a small quantity of electricity falling through a great difference of potential, and that for other purposes we must have a great quantity of electricity falling through a small difference of potential.

When we possess an electric circuit from a generator, we are able to convert the electric energy into other forms of energy at any place. In every part of the circuit some heat is being produced, and to produce a high temperature at any place it is only necessary to introduce a thin wire, say a platinum wire or carbon filament. Introducing an electro-motor at any place enables us to convert the electric energy into mechanical energy. Thus an electric generator receiving mechanical energy from a steam-engine gives out electric energy; this energy can be conveyed many miles along metallic wires to an electro-motor, which converts it into mechanical energy again. I think I shall never forget the astonishment of a workman in Sheffield, who had put up a saw-bench for use at a lecture by Professor Ayrton, and was about to rehearse his part of the performance to be gone through during the lecture. He looked at the motionless saw, and he laid his hand on the wood; he saw that there was a belt from a little mite of an electro-motor to the saw, two wires dangled from the ceiling to the motor, and this was all. He was evidently beginning to think that he was the victim of a hoax; but when at the distant place a water-engine was started to drive the distant machine, when the saw set off nearly at its full speed, and the two dangling wires were evidently the only means of communication, this thoughtful workman's face expressed only blank amazement and puzzled curiosity.

I have already observed that we have instruments which enable us to measure the electric power of the distant generator, the power wasted by conversion into heat in the circuit, the electric power received by the motor or lamp, or other useful converter, and the mechanical power or light or heat given out by the motor or lamp; and by easy reasoning we find out what are the conditions for the most efficient transmission of power.

In electric lamps we usefully convert electric energy into heat and light, although some of our energy is always being uselessly converted into heat in our connecting wires. One remedy is to make these connecting wires of very thick copper, but this is an expensive and only a partial remedy. The problem before us is this: Electrical energy may be transmitted to a distance, and even to many thousands of miles; but can it be transformed at the distant place into mechanical or any other required form of energy, nearly equal in amount to what was supplied? Unfortunately, in all actual experiments hitherto made, the waste in transmission has been very considerable; but, fortunately, we may have perfect faith in the laws already stated, and these laws tell us that such waste is not at all a necessity. We shall, I believe, at no distant date, have great central stations, possibly situated at the bottom of coal-pits, where enormous gas-engines will drive dynamo machines. We shall have wires laid along every street, tapped into every house, as gas-pipes are at present. We shall have the quantity of electric energy used in every house registered as gas is at present, and it will be supplied to electro-motors to drive machinery, to produce ventilation, to replace stoves and fires, to work apple-parers, and mangles, or such things as barbers' brushes, as well as to give everybody an

electric light. My reason for arriving at this conclusion is a very simple one. Suppose that there is an electric generator at Niagara, driven by a turbine water-wheel. Let there be wires to an electro-motor in New York, giving out mechanical power. The power received by the motor is proportional to the current multiplied by the motor's potential difference. The power wasted in heating the circuit is proportional to the square of the current. Hence, if a one horse-power motor has its potential difference increased, since it needs less current, and since the loss is proportional to the square of the current, there is less loss than before. In fact, by increasing the potential differences of generators and motors, we can reduce the loss of energy in transit as much as we please.

During the last six years the progress made in electric engineering has been mainly due to improvements in the mechanical arrangements of dynamo machines, electro-motors, arc and incandescent lamps, and in the electric supply cables used in general systems of electric lighting and transmission of power. These improvements have been effected almost altogether by mechanical engineers, whose knowledge of electrical science, ten years ago, was extremely insignificant. There can, therefore, be no doubt that in the hands of the numerous body of practical men who have a pecuniary interest in making such improvements, electrical engineering will rapidly become more important to the community than any other department of civil engineering. There are still difficulties due to the sparking of the brushes of dynamo machines and motors; short circuits occasionally occur through defective insulation of the wires with which machines are wound. The management of electric light installations, and electric railways, and systems of telpherage, cannot yet be left altogether to common stokers of steam-engines. But the time is rapidly approaching when the slight difficulties here referred to will have completely disappeared. This will take place in proportion as some real knowledge of the subject shall become more generally diffused amongst the practical workers therein, as already in part realised, and described in the earlier portion of this Introduction. Towards such an object it may be hoped that this book, giving as it does something like a connected view of the chief practical applications of electricity in man's service, with some explanation of the principles upon which they depend, and the manner in which the various quantities concerned in their proper adaptation are measured,* related, and adjusted, will in some degree contribute.

JOHN PERRY.

* As I think it of the greatest importance that readers of books on electricity should no longer have only vague notions of the magnitudes with which they deal, the table on the following page is put at once before their notice. The succeeding pages of the text will give more detailed explanation of most of them.

ELECTRICAL MAGNITUDES

(SOME RATHER APPROXIMATE).

Resistance of

One yard of copper wire, one-eighth of an inch diameter	0·002	ohms.
One mile of ordinary iron telegraph wire	10 to 20	,,
Some of our selenium cells	40 to 1,000,000	,,
A good telegraph insulator	4,000,000,000,000	,,

Electro-motive force of

A pair of copper-iron junctions at a difference of temperature of 1° Fahr.	0·000,01	volts.
Contact of zinc and copper	0·75	,,
One Daniell's cell	1·1	,,
Mr. Latimer Clark's standard cell	1·45	,,
Difference of potential at the terminals of an incandescent lamp used in ordinary lighting	50 to 110	,,
Board of Trade limit of difference of potential between any two points in an electric circuit used in continuous current lighting	200	,,
Electro-motive force of one of Dr. De la Rue's batteries ...	11,000	,,
Lightning-flashes	probably many millions of volts.	

Currents usually measured—

Using electrometer	almost infinitely small currents.	
Using delicate galvanometer	0·000,000,000,040	amperes.
Current received from Atlantic cable, when 25 words per minute are being sent	0·000,001	,,
Current in ordinary land telegraph lines	0·003	,,
Current through an ordinary incandescent lamp	0·5 to 1	,,
Current from dynamo machine used in electric lighting...	5 to 500	,,

In any circuit containing a generator of electricity, the electro-motive force of the generator is equal to the current in amperes multiplied by the resistance of the circuit in ohms.

The resistance (in ohms) of any piece of wire forming part of an electric circuit, is equal to the difference of potential (in volts) between its ends divided by the current (in amperes) passing through it.

Rate of production of heat or other forms of energy in watts (746 watts = 1 horse-power): In the whole of a circuit, is the current (in amperes) multiplied by the electro-motive force (in volts). In any wire forming part of a circuit, is the current (in amperes) multiplied by the difference of potential (in volts) between the ends of the wire, or the square of the current (in amperes) multiplied by the resistance (in ohms).

In a 20-candle incandescent light we find that 75 watts are usually expended.

Rate at which electric energy is given to an electro-motor, is the difference of potential at the terminals of the motor (in volts) multiplied by the current (in amperes). This energy is converted partly into heat and partly into mechanical energy by the motor.

Rate at which electric energy is being given out by a generator, is the difference of potential at its terminals (in volts) multiplied by the current (in amperes).

ERRATA.

Page 88, line 1, *for* "Dufay" *read* "Du Fay."
,, 153, line 39, *for* "Meivinger" *read* "Meidinger."
,, 178, line 23, and under diagram, *for* "Ball" Magnet *read* "Bell" Magnet.
, 206, line 40, *for* "Nobanitzky" *read* "Urbanitzky."
,, 211, line 26, ,, ,, ,,
,, 212, line 12, ,, ,, ,,
,, 360, lines 19, 21, and under diagram, *for* "British" *read* "Brush" regulator.
,, 401, line 8, *for* "Buschtetwarder" *read* "Buschtöhrader."

ELECTRICITY

IN THE SERVICE OF MAN.

PART I.

The Principles of Electricity.

EARLY HISTORY OF MAGNETISM AND ELECTRICITY.

Early and Classical References to Magnetism.—The ancients were acquainted with the natural loadstone, although we cannot determine the exact date when it was discovered. They had, however, very exaggerated notions of its powers. According to Plinius, the loadstone was first found by a shepherd named Magnes, and hence the term magnet. Other historians refer to the loadstone under the name of "Lithos Herakleia," which meant Hercules stone, or the stone of Heraklea. The town of Heraklea, at a later period, received the name of Magnesia, which may have been the origin of the word magnet. Lucrez (born 95 B.C.) mentions the fact that the loadstone had the power of attracting and repelling iron.

Klaproth attributes the discovery of the magnetic needle to the Chinese, as early as the year 121 A.D. Another Chinese work, dating from the eleventh century, mentions the fact that sailors made use of the magnetic needle, and are said to have been acquainted with its deflections. Magnetic needles were first employed by the Chinese on land journeys, and not sea voyages. The celebrated Tchi-nan-tschin had a magnetic needle, of which Poggendorff gives a description.

History of Magnetism during the Middle Ages.—Nothing certain is known about the exact period when the compass was brought to Europe. We find in a piece of poetry called "La Bible," composed by Guyot de Provins, dated 1190, some lines to the effect that sailors consulted the magnetic needle when bad weather set in. Jacques de Vitry, in his "Historia Naturalis" (1215—1220), mentions the magnetic needle as being at that time no longer a novelty.

The first European who took into account the declinations of the needle

was probably Christopher Columbus. Its deflection from the due north had been previously attributed to the incorrect construction of the instrument. Variations in the deflection of the needle at the same place were first noticed by Henry Gellibrand in the year 1634.

In the year 1544 the discovery of the inclination, or dip, was made by Hartmann, who mentions the fact in a letter to Albrecht of Prussia. Robert Norman (1576), in making more accurate experiments to ascertain the cause of "dip," found that iron, when magnetised, did not increase in weight. The reason for the inclination, or dip of the magnetic needle, was satisfactorily explained by William Gilbert, whom we shall have occasion to mention later on. Gilbert and Hartmann were aware that similar poles repelled each other. Gilbert observed, further, that pieces of iron vertically suspended became magnets, especially when the bar of iron had a similar inclination to that of the dipping needle, and that the poles of the magnets thus formed nearest the earth proved to be N. poles. From these facts he concluded that the earth was itself an enormous magnet; he therefore claims the discovery of the earth's magnetism. This affords an easy and satisfactory explanation for the increase of inclination from the equator to the poles. Hudson, the discoverer of the bay bearing his name, practically proved Gilbert's theory by his journey into northern latitudes in 1608. Gilbert also found that a bar of iron having the direction of the needle could be magnetised by hammering: the magnetism being lost when the bar was heated, but regained when the bar was cooled; in fact, that the bar might be magnetised again by making it red hot, and allowing it to cool whilst inclined at an angle equal to that of the dipping needle.

Early History of Electricity.—It is difficult to give the exact date at which the first observations of electrical phenomena were made. Thales, one of the seven sages of Greece, who was born at Mileta in the year 640 B.C., and who died in 548 B.C., is supposed to have been the first who observed that amber had the power of attracting small bodies. Amber was known to the Greeks by the name "elektron," and from this name the word electricity has been derived. The ancients must have been acquainted with the effects of atmospheric electricity, as thunder-storms in most southern latitudes are of frequent occurrence, and they also knew of the St. Elmo's fire. They could, however, have had but little or no knowledge of electricity, and the few phenomena above noticed, with which they were acquainted, they were quite unable to explain.

Gilbert's Discoveries.—The science of electricity remained in this condition for nearly two thousand years, when Queen Elizabeth's physician, William Gilbert, made a series of fresh discoveries of electrical phenomena, which won him the title of the founder of the science. He was born at Colchester in 1540, studied at Oxford and Cambridge, and, after travelling for some time on the Continent, established himself as a physician in London, where he died in 1603. Considering the period at which Gilbert lived, his scientific knowledge must have been remarkable. It gained for him the favour of the queen, who

gave him the means of carrying out his scientific experiments, and also appointed him her private physician. The principles and theories of Lord Bacon, who frequented Queen Elizabeth's Court, probably greatly influenced Gilbert. It is, however, certain that he did not follow the plan previously followed by the schoolmen, of making daring hypotheses to explain natural phenomena, but formed his ideas from direct experiment. This is exactly the plan adopted by Bacon. Gilbert discovered that other bodies besides amber could be electrified by friction. He also ascertained that the production of electricity was affected by moisture; that hot or burning bodies lost all electricity; and that an electrified body attracts a variety of other bodies, whereas a magnet only attracts steel or iron. The latter fact shows that he was acquainted with the difference between electricity and magnetism.

The Jesuit Nicolo Cabeo, Francastro, Descartes, and others studied electricity, but were satisfied to establish learned theories without testing them by actual experiments.

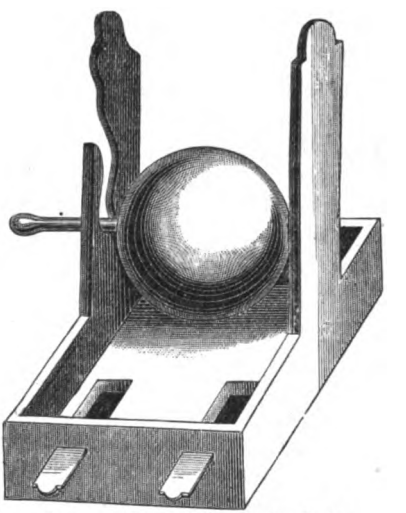


Fig. 1.—Guericke's Sulphur Ball.

Guericke's Sulphur Ball.—The next scientist who increased the list of important electrical discoveries was Otto von Guericke. He was born at Magdeburg in 1602, studied law at Leipzig and Jena, and mathematics and mechanics at Leyden. After visiting France and England, and being employed as engineer at Erfurt, he returned to Magdeburg, where he was elected mayor, and where he afterwards made his experiments. In 1681 he removed to Hamburg, where he died five years later (1686). Up to this time electricity had been produced by taking larger or smaller pieces of various substances in one hand, and rubbing them with the other, the amount thus obtained being very small indeed. Guericke now, however, to his other discoveries, added that of an electric machine. Having cast a globe of sulphur, he supplied it with a wooden axle, and then mounted the whole on a frame (Fig. 1), the hand being employed as the rubber. Although the arrangement was a very simple one, he obtained better results with it than any of his predecessors. By means of it he discovered that the production of electricity in large quantities was accompanied by light and sound. He further found that the electrified sulphur globe attracted light bodies, which it afterwards repelled until they had touched some other body.

Discovery of Electrical Luminosity.—About the same time Picard observed the luminosity of greatly rarified gases. Experimenting with an imper-

fectly exhausted barometer tube, he agitated the mercury in the tube, thus producing electricity, which caused the mercury vapour and the remaining air to glow.

Robert Boyle and Dr. Wall made further discoveries, the former finding that substances are attracted by an electrified body in a vacuum, while the latter was the first to produce the electric spark.

Hawksbee, who lived at the commencement of the eighteenth century, gave the first proper explanation of Picard's observations. He experimented in the following manner: Taking several glass vessels containing mercury, he exhausted the air by means of an air-pump, and then agitated the mercury. The glow which was thus produced inside the vessels he attributed to electricity, and to test the point he was led to construct an electrical machine. He substituted a glass globe for the sulphur ball of Guericke, which he exhausted, and thus obtained, besides the glow, sparks an inch long. He also experimented with other substances, such as sealing-wax, etc., from which he discovered that the electricity of these bodies was not of the same character, though he did not go so far as to recognise the positive and negative electricities.

Stephen Gray (1696—1736), about whom little is known, was the first to draw attention to the classes of conducting and non-conducting bodies. Experimenting with some glass tubing, the ends of which he closed with corks, he found that although the corks were not rubbed, they attracted and repelled small bodies exactly like the excited glass tube. He followed this discovery up, and proved the difference between conductors and non-conductors, or insulators. He also ascertained that it was not necessary to touch the bodies for the purpose of charging them, and further, that the distribution of electricity on a body was unaffected by the mass of that body.

Discovery of the fact that Electricity is of two kinds.—Charles François de Cisternay du Fay, better known under the simple title of Du Fay, made experiments during the years 1733—1739. He found, as the result of his investigations, that electrified bodies attract all unelectrified bodies, electrifying them in turn, and then repelling them; also that there are two distinct kinds of electricity—namely, that which is produced by rubbing glass, etc., and that which is produced by rubbing amber, resin, sealing-wax, etc. He termed the former kind vitreous electricity, and the latter resinous electricity. His experiments on living bodies produced a great sensation at the time.

The Globe Electric Machine.—It is a curious fact that these men were content to produce the required electricity by means of a rubbed glass rod, and none of them thought of perfecting Guericke's and Hawksbee's electrical machines. Litzendorf, a pupil of the mathematical Professor, Christian August Hansen, proposed to use in the place of the glass rod a glass ball, which might be rotated by means of a wheel. The professor carried out the suggestion, and thus the glass ball was employed a second time, but the hand was still retained as the rubber.

The Prime Conductor.—Professor George Mathias Bose, who died in

1761, constructed the first prime conductor, which was simply an iron tube, held by a person who stood on a cake of resin. This method of supporting the conductor he soon found to be inconvenient, and he therefore suspended it by silk threads. Observing that the person rubbing the glass ball became charged with electricity as well as the conductor, he put a kind of armour all over the person and let him stand on a large cake of resin. When charged, the person began to glow all over, the effect terminating with a kind of halo round the head. This experiment was known under the title of the "beatification." He also succeeded in firing gunpowder.

Cylindrical and Plate Machines.—Professor Andreas Gordon, of Erfürt, changed the glass globe for a glass cylinder; and Giessing, under the direction of Professor Johann Winkler, of Leipzig, constructed a cushion, or rubber, which consisted of some woollen material held in position by metal catch springs. The electrical machine now possessed both rubber and prime conductor. Benjamin Wilson (1746) improved the conductor by adding a series of points, which he termed the collector; and Canton (1762) improved the rubber by the addition of amalagam of tin. With the machine as thus improved very fair results were obtained.

Several claim to have been the first to use a glass plate instead of a glass cylinder, but Poggendorff says that Planta was the first who made use of the plate machine. Several machines with very large plates were constructed; the Duke de Chaulnes made a machine, the plate of which had a diameter of nearly five feet; this machine gave sparks of twenty-two inches in length.

The Electric Jar.—We come now to the discovery of the electric jar. According to our authority, Poggendorff, Dean Kleist was the inventor of the electric jar. In 1745 Kleist brought near his electrical machine a medicine-bottle, in the neck of which there happened to be an iron nail. Holding the bottle with one hand, the other happened to touch the nail, and, to his surprise, he received a violent shock; he made several experiments to trace the cause, and communicated with several people regarding them.

About the same time Pieter van Musschenbroek made the same discovery. Musschenbroek, Professor at Leyden, observed that electrified bodies lose their electricity when exposed to the atmosphere. To prevent the electricity from leaving some water, he put the water into a glass bottle, and conducted the electricity along an iron nail. Cunaens at Leyden, who worked with Musschenbroek, happened to hold this bottle in one hand in order to charge it, and on removing the bottle from the conductor he touched the conducting wire with the other hand; he then received a shock like Kleist. Musschenbroek repeated the experiment, but got so frightened that he wrote to Réaumur: "not for the imperial crown of France would he expose himself a second time." Réaumur mentioned the fact to the Abbot Rollet in Paris, and he it was who introduced the term Leyden jar. Winkler, Grabath, Le Monnier, Bevies (especially Winkler in Leipsig) worked at the subject. Dr. Bevies conceived the happy thought of covering the outside of the jar with tinfoil. After some time

he tried to charge a glass plate covered on both sides, and received when discharging it a violent shock. This caused Watson to construct for the first time a perfect Kleist, or Leyden jar. Watson covered earthenware vessels with tinfoil almost up to their edges; he knew that the efficiency of the jar depended on the surface of tinfoil, but about its mode of action he had no notion.

Franklin's Discoveries.—Benjamin Franklin explained this, and made important discoveries regarding the Leyden jar. He found that an insulated ball, after contact with the inner coating of the jar, was repelled by the outer coating, and *vice versâ*. He suspended a cork ball, which received its charge from the outer coating, and found it to be repelled by a wire in connection with the inner coating; he further made wires from the outer and inner coating come within an inch or so of each other. Between these wires he suspended the cork ball, which oscillated until the jar had lost all its electricity. On the basis of these experiments Franklin tried to explain the behaviour of the Leyden jar. At the same time he laid down a law of electricity, that when two oppositely charged conductors, separated by an insulator, are brought near together they will attract each other. Franklin, one of America's greatest citizens, was born in 1706. On his statue is the appropriate epitaph, "He snatched the lightning from heaven, and the scepter from tyrants." His crowning invention was the lightning conductor. He thought lightning to be nothing more than an enormous electrical spark, though he was not the first to entertain this idea; we know that Wall, Rollet, and Winkler, in particular, reasoned in the same manner; but he was the first to give clear and distinct explanations, and to propose experiments to prove them. Franklin was however forestalled in the experiment which he proposed; the first who actually made the experiment were the Frenchmen, Dalibrand and Delor. Franklin, for the purpose of verifying his theories, commenced experiments (1752), which enabled him to give directions for the practical construction of lightning conductors. He reasoned thus: Knowing that lightning and the sparks produced with the electrical machine were identical, he thought if it were possible to conduct electricity from the clouds, it would be equally possible to rob it of its destructive power. A spark being only produced along a conductor that has a break in it, or which is too weak in itself to render this electrical spark harmless, it would only be necessary to use metal rods of sufficient strength, and to have them well connected with the earth. Winkler, in Germany (1753), warmly urged the erection of lightning conductors. Through his influence a clergyman had the first lightning conductor erected near his house. Unfortunately, the summer of 1756 being very dry, the superstitious peasantry ascribed it to this weather rod, and were not satisfied until they saw it removed.

Richmann's Death.—Professor Richmann, at Petersburgh, had in his room an insulated iron rod erected for the purpose of studying atmospheric electricity. During a thunderstorm in August, 1753, Richmann approached to observe his rod, when a large spark or ball of fire rushed from it and killed him on the spot. His engineer, Sokoloff, who was present at the time, was thrown

to the ground, but recovered after a short time. De Romas, in France, experimented on atmospheric electricity, but with greater care. Like Franklin, he used a kite of large dimensions. The line by which he held this electrical kite had wire twisted round it, and terminated in a rope of silk; to the extremity of this wire rope he attached a cylinder of sheet-iron. With this apparatus he obtained remarkable results. In August, 1757, by using a similar discharger, he obtained sparks ten feet long. The sad fate of Richmann caused great sensation, but did not prevent men like Le Monnier, Beccaria, and Cavallo from continuing their experiments.

The use of electricity in medicine was brought forward, and ways of measuring electricity were diligently tried.

Electrometers.—The first electrometer was constructed by John Canton (who lived from 1718 to 1772 in England); it was the well-known pith-ball electrometer. Several others constructed electrometers in principle like Canton's.

Repulsion between two pith-balls was observed when a charged body was brought near them; this phenomenon was studied and explained by Æpinus and Wilke. They further proved that one of Franklin's notions about the Leyden jar was incorrect, for he attributed the behaviour of the jar to the peculiar structure of the glass.

Symmer's Theory.—The science of electricity was advanced not a little during the period of silk stockings. Robert Symmer (1759) used to wear silk stockings, and always two pairs at a time, one white and the other black; whenever he pulled one pair from the other he heard a crackling noise, which he attributed to electricity; he found also that stockings of the same colour repelled each other, and those of different colours attracted each other. Although these facts proved nothing new, Symmer was led to take up again Du Fay's theory, that there are two different kinds of electricity. To prove his theory Symmer could only think of one experiment. He sent a spark through paper and examined the perforation. The edges of the hole which the spark had made were turned up on both sides of the paper. According to Franklin's theory, this fact could not very well be explained: Symmer explained it by assuming that "in an electric discharge two streams of electricity flow in opposite directions." Although he could only propose this one experiment to maintain his theory, electricians considered it conclusive. Franklin was kind enough to send Symmer an apparatus which he thought might aid him in establishing his theory, though opposed to his own. Symmer's, or rather Du Fay's theory, received further support by Lichtenberg's discovery of electrical dust figures in 1777. These dust figures assume different shapes when first produced by positive, and then by negative electricity, and *vice versâ*. Lichtenberg also introduced the terms + and −.

The charging of coated insulators and the improvement of measuring instruments now received attention. Volta constructed the electrophorus, which led him on to the discovery of the condenser, an instrument which condenses

or accumulates electricity. Volta, in 1781, also devised the straw electroscope. Both Bennet and Volta thought of using the condenser and electroscope combined.

Coulomb's Balance.—After Coulomb's researches, nothing was added to the knowledge of statical electricity for a considerable time. Charles Augustin de Coulomb (born in June, 1736) published in 1784 the results of his celebrated researches on the force of torsion and elasticity of metal wires. He constructed shortly afterwards the torsion-balance, an instrument still in use.

Animal Electricity.—Some electrical phenomena in the animal kingdom next received attention. Réaumur (about 1714) pointed out that the electrical shad-fish was capable of imparting violent shocks. These he attributed to the muscular power of the animal's tail. It was afterwards assumed that these shocks might be of an electrical nature, and this was proved experimentally by Dr. John Walsh in 1772. He experimented on the electrical shad-fish, and showed that in order to obtain the shock the fish must be touched on both sides at the same time. Many experiments in different directions were made to solve the problem as to the source of the electricity of the torpedo and electric eel, but even up to the present time much uncertainty prevails.

Galvani and Volta.—Luigi Alvisio Galvani (born 1737) made some important discoveries through noticing the motions of a frog's leg. The publication of his experiments and explanations were much talked of, and a scientific war commenced between Galvani's and Volta's followers. Alessandro Volta was born 1745, he first publishing the results of his researches between 1769 and 1771, which brought his name before the public. Poverty and disease prevented Galvani from following up his discoveries. Volta made experiment after experiment, which ultimately resulted in the discovery of the pile. In 1800 he informed the Royal Institution, London, of his invention. The value of Galvani's and Volta's discoveries is best understood in following the further growth of that particular branch of electrical science which is termed Galvanism. Volta and Galvani no doubt laid the foundation, but to complete the structure required such men as Oersted, Ampère, and Faraday.

Oersted's Discovery.—It has been said that an apple falling to the ground caused the discovery of the law of gravitation; the motion of a frog's leg led to the discovery of galvanism; chance led Oersted to observe the influence an electrical current has on the magnetic needle. Are all these discoveries to be attributed to chance only? and how is it to be explained that these so-called chances only happen with great men? Whewell says, in his "History of Inductive Science," "These accidents, if accidents at all, are more like the spark that sends the charge of a gun to a directed aim."

Hans Christian Oersted was born 1777; his most important discovery was that of electro-magnetism (1819). Oersted's discovery explains the behaviour of iron rods through which lightning had passed, and also explains the polarisation of magnetic needles. Ampère took great interest in Oersted's discoveries, and through them was finally led to his celebrated theory of electro-dynamics.

Ampère's theory was not so readily accepted by his contemporaries as might have been expected. In 1822 Sweigger constructed a galvanometer, and Professor Seebeck discovered thermo-electricity. Georg Simon Ohm, born 1787, laid down a law (1827) for galvanic batteries, and Arago published the results of his researches on Rotation-magnetism.

Properly speaking, the early history of electricity comes to a close here, and the science of electricity commences with the results of the researches of Davy and Faraday. The one who, as it were, prepared the ground was Humphry Davy (born 1778). His researches regarding the influence of the electrical current on chemical compounds were begun in 1806, and led him to the decomposition of the alkaline earths and the discovery of the alkaline metals. Chlorine was found to be an element, and the products of decomposed bodies to be analogous to positive and negative electricity, etc. etc. This observation led to the electro-chemical theory. Although water was decomposed by Carlisle and Nicholson in 1800, no proper explanation of the result could be furnished. Davy, however, proved water to consist of oxygen and hydrogen only.

We owe to Faraday, his pupil, the further working out of Davy's notions. Michael Faraday (born 1791) was no doubt one of the greatest physicists that ever lived. We need not go into the details of his discoveries in many other branches of science. For us, his name is chiefly associated with the law of electro-statics, diamagnetism, and induction. The enormous importance of this discovery of induction may easily be seen by pointing to the present condition of electro-technics, *i.e.* to the telegraph, telephone, and dynamo machine.

Faraday substituted the term electrode for pole, naming the positive electrode the annode, the negative electrode the kathode. He also constructed the voltameter, by means of which he discovered the laws of electrolysis in 1853.

MAGNETISM.

The Loadstone.—There is an ore in nature termed by mineralogists magnetic iron-stone, which possesses certain remarkable properties. If we take a piece of this ore which has been shaped a little, and plunge it into iron filings, fringes of the filings adhere to it. If we suspend it, so that it can turn freely, as by placing it in a chair or saddle of paper hung by a fine thread, or by floating it on cork, it sets itself in a fixed direction, pointing nearly north and south. All these properties we imply when we call it a loadstone, or natural magnet. If we draw the point of the loadstone three or four times along a small sewing-needle from the eye to the point, it communicates its properties to the needle. The loadstone gives the needle some power it had not before. We describe what we have done to the needle by saying we have magnetised it, or have imparted magnetism to it. Hence we have *natural* magnets like the loadstone, and *artificial* magnets like the sewing-needle. For the future we shall employ, in the place of our irregularly-shaped natural magnet, a regular bar of steel, made a magnet by being drawn across another magnet. An artificial

magnet, such as this bar magnet, possesses the same three properties as the loadstone: 1. It attracts iron. 2. When suspended, it yields to the directive force of the earth. 3. When we draw it along a piece of steel, it makes the steel a magnet.

The Poles of a Magnet.—Some simple experiments will help us to examine more clearly these magnetic phenomena. Fig. 2 represents an iron ball suspended by a silk thread from a wooden stand. If we bring near this iron ball a magnet, the iron ball is attracted by it, and held in contact. If we substitute other substances, as stone or brass, for the iron, the magnet exercises no power over them. If we now suspend the magnet in the same way, and bring a piece of iron near it, the magnet moves towards the piece of iron. From these experiments we conclude that the iron and the magnet attract each other, but that the magnet is not influenced by other substances. If we now bring near different parts of the magnet our iron ball, we soon observe that the two ends of the magnet influence the iron ball at a considerable distance, whilst the centre of the magnet has no power

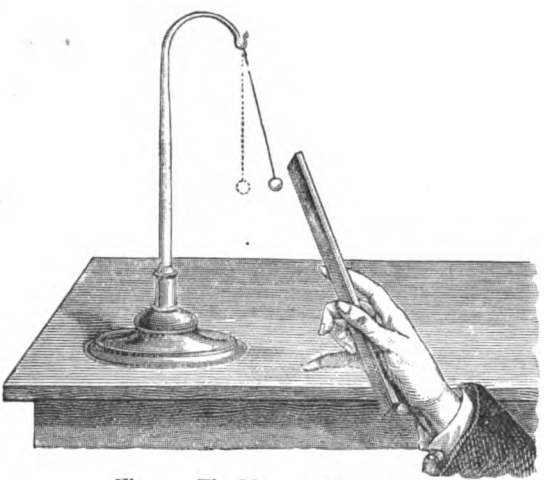


Fig. 2.—The Magnetic Pendulum.

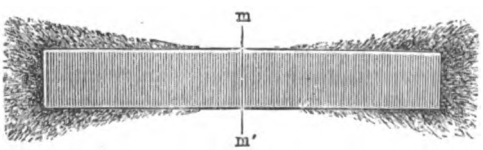


Fig. 3.—Magnet and Iron Filings.

over the ball. The magnetism is thus not evenly distributed over the bar. The law of distribution of magnetism along the magnet is roughly shown by plunging the magnet in iron filings, when they adhere to it in the manner shown in Fig. 3. The fringe of iron filings is thickest at the ends of the magnet, while in the centre there are none. The extremities of the magnet are termed poles; the space indicated by the line $m\ m^1$ is termed the neutral line, or neutral zone.

Declination.—We further observe that our suspended magnet (free to turn) takes up a definite position relatively to the earth. The pole pointing

towards the north pole of the earth we term the north-seeking pole, and that pointing to the south we term the south-seeking pole. Exact measurements, however, have shown this direction *not* to be *exactly* north and south; and the angle contained by the magnetic needle and the true meridian is called the declination.

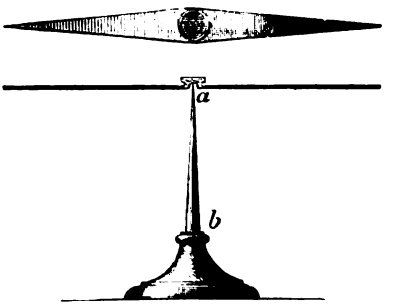


Fig. 4.—Declination Needle.

Inclination, or Dip.—We find, further, that the suspended magnet does not remain horizontal; the angle which the axis makes with the horizontal plane is the dip, or inclination. In our latitudes the north-seeking pole points downward.

Declination and inclination vary with time and place. The magnetic declination, for example, at Vienna at present is: 10° W.; inclination, 63°. At Berlin declination is 12°; inclination, 67°. The declination for Europe, Africa, and the Atlantic Ocean is west; that is, the north-seeking pole of the needle points west of true north. The declination for America and Asia is east. In the northern hemisphere the north-seeking pole points downward; in the southern, the south-seeking pole points down.

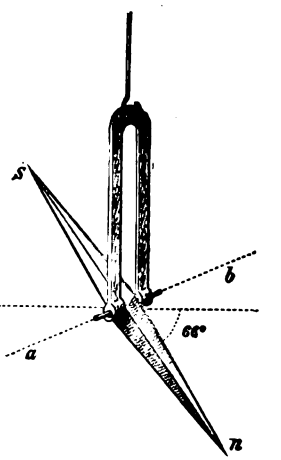


Fig. 5.—Inclination Needle.

Magnetic Needles.—The form of a magnetic needle arranged to show the declination is represented in Fig. 4, where the needle moves upon a perpendicular axis or pivot *a b*. A dipping needle arranged to show the inclination is shown in Fig. 5, where the needle *s n* turns upon the horizontal axis *a b*. Fig. 6 represents a simple compass. It consists of a magnetic needle resting on a steel pivot, protected by a brass case covered with glass, and a graduated circle marked with the letters N, S, E, W, to indicate the cardinal points; *a b* is a lever which arrests the needle by pushing it against the glass when the button, *d*, is pressed. The mariner's compass is more complicated; it generally consists of a card pivoted on a vertical axis, and directed by having on its lower surface two or more parallel magnets. The upper surface of the card is divided into degrees, and also into thirty-two parts of $11\frac{1}{4}°$ each. The presence of any iron or steel in the neighbourhood of the compass alters the direction of the magnetic force, and causes what is termed a deviation of the north and south line from the magnetic meridian.

Mutual Action of Magnets.—It has been said that a magnet possesses the power of attracting iron, the force with which it does this being strongest

nearest the poles, and diminishing towards the middle until it becomes zero. There is no difference between the poles of a magnet in this respect, but there is a further action between magnets, which we now proceed to describe.

Having marked the north-seeking end of two magnets, let us suspend one of them. If we bring a piece of soft iron first to one end and then to the other, we find that it is attracted at both. Now take up the other magnet, and present its marked end to the similar pole of the suspended magnet. The resulting action is not attraction, but repulsion. If we turn the unmarked end to the unmarked end, the one repels the other, as before. If we next bring the marked end of one to the unmarked end of the other, we get attraction and not repulsion.

Hence, there is a difference in the actions on a suspended magnet of a non-magnetised piece of iron and of another magnet. The non-magnetised piece of iron attracts both poles, but the action between two magnets is not quite so simple. Between magnets similar poles repel, but dissimilar poles attract; thus the north-seeking end repels the north-seeking end, the south-seeking end repels the south-seeking end, while the north-seeking end attracts the south-seeking end, and *vice versâ*.

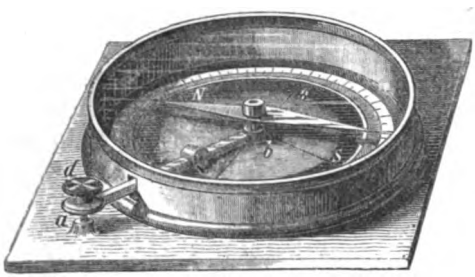


Fig. 6.—Simple Compass.

The Earth a Magnet.—This difference between the poles accounts for the fact that when a magnet is free to move it invariably takes the position pointing north and south. Since magnets at all parts of the earth tend to take up this position, it follows that the earth itself must possess a distinct magnetic north pole and a magnetic south pole. Careful experiments at various parts of the earth, however, have proved that the magnetic poles of the earth do not correspond with its geographical poles, the magnetic north pole being situated in lat. 70° 5′ N., and long. 96° 46′ W., or to the north-west of Hudson's Bay. The magnetic south pole of the earth has never been reached, but it appears from the distribution of magnetism as if there were two magnetic south poles.

Here we encounter a difficulty; it follows from what we have stated that the magnetism of the magnetic north pole must be opposite in character to that of the north-seeking end of the magnet, and similar to that of the south-seeking end. In what terms, then, are we to distinguish between these opposite kinds of magnetism? We cannot at the same time call both the north-seeking pole of a magnet and the pole of the earth to which it points north poles, for the poles that attract each other are dissimilar. There are various methods of getting over this difficulty, but as they always lead to some complication or confusion, we shall merely refer to the ends of the magnet as north- and south-

seeking ends, and ask the student to bear in mind that the north magnetic pole of the earth and the north-seeking pole of a magnet have magnetism of opposite character—they are dissimilar poles.

Magnetic and Magnetised Bodies.—The behaviour of magnets towards one another enables us to ascertain the magnetic condition of any piece of iron. First present the north-seeking end of the magnet and then the south-seeking end to the piece of iron; if the piece of iron attracts both poles, it is unmagnetised, that is, it is not a magnet; but if it attracts either of the poles of the magnet, and repels the other, then it is a magnet having a north-seeking and a south-seeking magnetic pole.

Magnetic Induction and Distribution.—If we continue and vary the above experiment we find that a piece of soft iron in the presence of a magnet is not only attracted, but becomes a magnet itself, capable of attracting another piece, which again might attract a third piece of iron, and so on; only the magnetic strength of each succeeding piece is less than that of the preceding one. On the magnet being withdrawn, all these pieces of iron become detached from each other, showing that they were only magnetised when the first piece touched the magnet. Again, if we suspend an iron bar over a surface covered with iron filings, the filings and iron bar have no action upon each other; but if we now suspend a magnet over the iron bar the filings are attracted by the iron bar even when it does not touch the magnet. This effect is not lessened by placing between bar and magnet a sheet of glass, wood, or pasteboard. The filings, however, fall from the bar immediately on the magnet being withdrawn. If we want to ascertain the magnetic condition of the bar of iron whilst the magnet is above it, we can do so by means of a declination needle, and we find that the pole nearest the south-seeking pole of the magnet exhibits south magnetism, and the opposite pole north magnetism.

From this we see the bar of iron has become a magnet for the time being, without actually being touched by the magnet. During all these experiments the original magnet may be observed to have lost nothing of its power. It is neither weakened by being used to magnetise a piece of steel, nor by acting inductively on soft iron. When pieces of iron are brought near a magnet, the magnetism of the magnet does not flow over to the piece of iron, but the latter becomes a magnet by induction. The vertical bars of iron railings often become magnetised in our latitudes, the lower ends having north-seeking magnetism and the upper ends south-seeking magnetism. The magnetism of the earth in the northern hemisphere draws the north-seeking magnetism in the bar towards its lower end, whilst the south-seeking magnetism in the bar is driven towards its upper end.

Magnetism not a Fluid.—If magnetism were some kind of fluid which flowed over from the one body to the other during the process of magnetisation, we should have observed some signs of magnetisation in the wood, glass, or pasteboard sheet which we placed between the iron bar and the magnet;

but these did not show the slightest signs of magnetisation. Again, the piece of iron magnetised could have only one kind of magnetism, depending upon which pole of the magnet touched or was near the piece of iron; but this we observed was not the case. Lastly, the magnet would lose some of its power at each experiment, and, on the other hand, the piece of iron would give signs of magnetisation when removed from the magnet, at least for some time.

The phenomena observed in the previous experiments are explained by assuming that every piece of iron has both kinds of magnetism, equally dis-

Fig. 7.—Magnetic Induction.

tributed in all parts of the piece; consequently, the two opposite kinds of magnetism, when the iron is unmagnetised, neutralise each other, and, therefore, the piece of iron appears unmagnetised. This may be shown by magnetising a piece of watch-spring, and then bending it so that the two poles come together. On dipping these poles when in this position in filings, it will be found that no filings adhere to them, and no signs of magnetism are exhibited by the piece of watch-spring.

If we bring a magnet near to or in contact with a piece of soft iron *a b* (Fig. 7), the two kinds of magnetism in the iron are separated, and the kind of magnetism opposite to the approaching or nearest pole of the magnet struggles to get nearest it, and the similar kind of magnetism to that of the approaching pole tries to get away from it. The piece of iron therefore becomes a magnet, with exactly opposite poles to the magnet itself, as may be seen in Fig. 7. When the magnet is removed from the piece of iron, the two kinds of magnetism in the latter tend to demagnetise it again. In this manner magnetic attraction is explained: it may be represented as the tendency of two opposite poles, one of which is produced by the induction of the other, to attract each other.

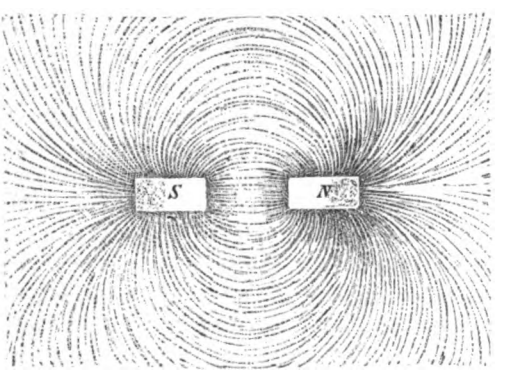


Fig. 8.—Magnetic Curves.

Lines of Force.—This will also explain the position iron filings take up when placed on a surface which is influenced by a magnet. If a small suspended magnet be carried round a large bar magnet, each pole of the small magnet is attracted by one pole and repelled by the other pole of the stationary magnet. The two forces on each pole have a resultant which causes the small magnet to

take up a definite direction for each position. A curve drawn so that each of these directions of the needle forms a tangent to it is termed a curve of force.

A much readier method of showing these curves or lines of force is to place a bar or horse-shoe magnet under a sheet of paper, and sprinkle iron filings over it. The filings will arrange themselves as they rebound from the paper and come to rest in a series of beautifully regular curves, which were first termed lines or curves of force by Faraday. Fig. 8 exhibits the manner in which the filings arrange themselves about a horse-shoe magnet. Different curves may be obtained by placing two magnets side by side with unlike poles adjacent, side by side with like pole adjacent, also by placing the magnets end to end instead of side by side and so on.

Another illustration of the magnetic induction that leads to the arrangement of the filings in the form of curves may be shown by the following experiment. (*See* Fig. 9.)

If two pieces of iron are suspended by means of silk threads, on the north-seeking pole of a magnet being brought near them they become magnetised, and in both we find the north-seeking pole farthest from the north-seeking pole of the magnet, the south-seeking pole nearest the north-seeking pole of the magnet. Since similar poles repel each other, it follows that the suspended pieces of iron diverge. The filings in the magnetic curve represent such magnetised pieces of iron, each in turn becomes a magnet, and the magnetic curves must diverge exactly like the bars in our illustration.

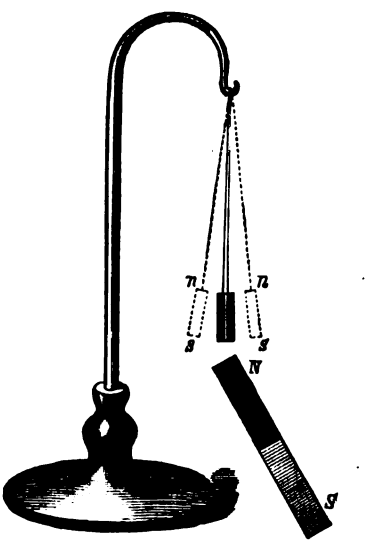


Fig 9.—Magnetic Double Pendulum.

It has been ascertained by experiment that in soft iron the separation of the two kinds of magnetism takes place easily and quickly. When under the influence of a magnet, a bar of soft iron becomes a magnet quickly itself, but it becomes demagnetised as quickly when the influencing magnet is removed. It is also ascertained that it takes considerably longer to magnetise annealed iron or steel, and also to demagnetise it. The magnet made of soft iron is termed a temporary magnet, and the steel magnet a permanent one. No ordinary piece of iron after once being magnetised loses all its magnetism, and no piece retains the maximum amount of induced magnetism. The magnetism which thus remains is called *residual magnetism.* The cause of this phenomena appears to be some kind of molecular resistance which occurs among the particles of the iron, and this force, which opposes magnetisation or demagnetisation, is termed *coercive force.* The kind of iron in which this force is greatest retains its magnetism best.

Theory as to the Constitution of Magnets.—We might find an explanation of some of the facts we have observed by the assumption that there is some kind of fluid, or ether, or whatever we like to call it, flowing from one magnet to the other; but the phenomena of induction have shown us the impossibility of such an assumption. The following facts will lead us to a more satisfactory explanation of the constitution of magnets. If we break a long, thin magnet, such as a magnetised knitting-needle, at the middle, or neutral line, we obtain two magnets, each of which has a north- and a south-seeking pole. Let these two pieces be again broken, then each of the smaller pieces thus obtained will be a magnet, both its ends attracting filings, while the north-seeking pole points in the same direction as the north-seeking pole of the original magnet, and the south seeking-pole in the same direction as the south-seeking pole in the original magnet, as shown in Fig. 10. If we consider this

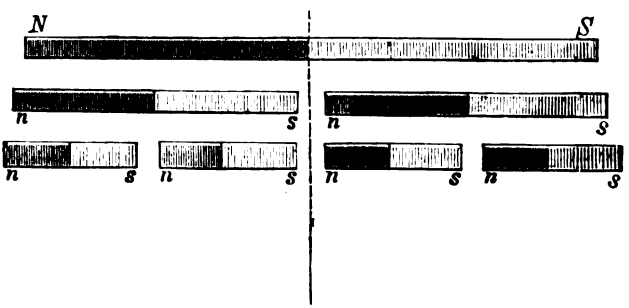


Fig. 10.—Effect of Breaking a Magnet.

to be continued till the portions become infinitely small, we are led to the conclusion that a magnet consists of little parts, or molecules, each of which possesses a north- and a south-seeking pole, and that all the north-seeking poles lie in one direction, and all the south-seeking poles in the opposite direction. There is a free north-seeking pole at one end, and a free south-seeking pole at the other, but every intermediate north-seeking pole is neutralised by the presence of an adjacent south-seeking pole.

According to this theory, it is not difficult to explain the different magnetic phenomena we have noticed, as, for instance, the action of magnetic induction. If we bring a piece of iron near the south-seeking pole of a magnet, all the south-seeking ends of the molecules of the magnet are directed towards the piece of iron, and as they are nearer than their north-seeking poles, their influence therefore prevails. The molecules which are at first scattered over the iron with their poles pointing in all directions, when under induction turn their north-seeking poles towards the magnet. The end of the piece of iron nearest the magnet will exhibit magnetism opposite to that of the pole to which it is presented. According to this view, magnetisation is nothing more than a determined position of all the molecular magnets, all their north-seeking poles pointing in one

direction, whilst their south-seeking poles point in the opposite direction. A piece of iron is in an unmagnetised condition when the molecules assume various and mixed directions. This may be proved by a simple experiment. If we nearly fill a glass tube with steel filings which have been magnetised, and pass the pole of a magnet along the tube several times, the tube of filings will behave like any ordinary bar magnet. The filings are now turned with their poles facing the same way, but if we now shake the filings in the tube it loses its magnetism, as the poles of the particles of filings are no longer turned in the same direction.* In the same simple manner the existence of the neutral zone may be explained. When we bring a piece of iron near the middle of a magnet, as at M M (Fig. 3) it is not influenced, because there are an equal number of particles on each side of that line having poles producing equal and opposite effects.

According to Ampère's theory, the magnetism of the molecules is caused by electric currents which circulate in them; this we shall consider in a later chapter.

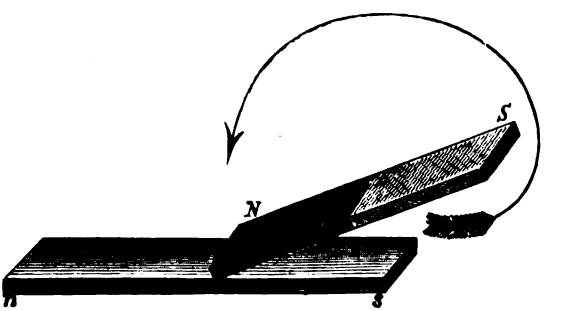


Fig. 11.—Single Touch.

Methods of Making Magnets.—Pieces of steel and iron, as we have previously stated, may be turned into magnets, the former into permanent, the latter into temporary magnets. There are three methods of magnetising steel by means of permanent magnets; they are termed the single touch, double or divided touch, and the circular touch.

Single Touch.—Place one pole of a magnet at the middle of the piece of steel to be magnetised, as shown in Fig. 11. Then draw the magnet from the middle towards the end of the piece of steel; repeat this several times, but take the magnet off at every stroke, and always draw the magnet from the middle towards the end of the piece of steel. In this case we obtain a south-seeking pole at the end of the bar at which the north-seeking pole of the magnet is drawn off, all the south poles of the molecules of the steel being turned towards this end. Next take the second pole of the magnet (in our case the south-seeking pole), and place it in the middle of the steel, and draw it along the bar in the opposite direction; we shall thus obtain a north-seeking

* The following experiment favours this hypothesis. A glass cylinder is fitted with flat glass ends, and is filled with water in which magnetic oxide of iron is diffused. A coil of insulated wire is wound round the cylinder. On looking at a light through the ends, the liquid appears muddy, and very little light can get through; but when a current of electricity traverses the wire, the liquid appears clearer and more light passes. The reason is that the particles of the oxide on being magnetised arrange themselves so that their lengths are in the direction of the axis of the cylinder, and so they obstruct less light.

pole. The magnet, during the operation, does not lose any of its power. It is a matter of indifference which of the poles is taken first. The same result may be obtained in several other ways: for instance, by placing two magnets on the steel and drawing them simultaneously from the middle towards the ends of the steel.

Double or Divided Touch.—Arrange the bar of steel and magnets as shown in Fig. 12. The magnets make an angle of about 20° with the steel bar, and between them is a piece of wood, shaped as in the figure; now move magnets and wood from the middle towards one end of the steel bar, then back again to the middle, and from the middle towards the remaining side of the bar; repeat this until the bar seems to take up no more magnetism, then take off both magnets at the same time, but from the middle. A horse-shoe may also be used instead of the bar magnets.

Circular Touch.—Let four bars be placed in the form of a rectangle (or two, that have the shape of a horse-shoe, in an oblong). Place a magnet at

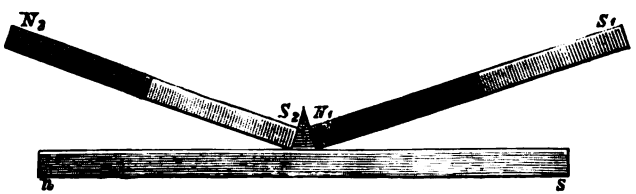


Fig. 12.—Divided Touch.

any point and draw it round the figure. Take off the magnet exactly where you commenced, and at that spot you will have a pole opposite to the pole of the magnet you operate with. The circular stroke may be used upon one bar only, having the shape of a horse-shoe, if provided with an armature, which is a piece of soft iron.

The chemical composition, hardness, and dimensions of the piece of steel to be magnetised ought to be taken into consideration, in deciding the method to be adopted. After a piece of steel has received a certain number of strokes with a magnet of a certain power, it becomes a permanent magnet, and is said to be saturated. This, however, does not mean that the piece might not be made more powerful by using a more powerful magnet. Again, the strength of magnetism produced cannot be extended beyond a certain limit, no matter how powerful the magnet we use. This limit is called the maximum of saturation. The hardness of the steel, the manner in which it has been hardened, and the amount of carbon in it, influence the limit to which it can be magnetised. The magnetism is increased when the steel is rich in carbon, and when it is very hard. When the steel is without carbon its hardness greatly influences the result; when rich in carbon, this influence of its hardness is not so great. The tempering, etc., of the steel is also to be taken into consideration. Owing to these and other causes, it is impossible to lay down exact rules for the

production of powerful magnets. According to Jamin, hard steel, rich in carbon, is best for permanent magnets. Cast iron is capable of receiving permanent magnetism, but its maximum of saturation is not great.

Bars of steel often become magnetised by hammering, friction, etc. The magnetism in a piece of steel is weakened by heating the steel, entirely destroyed by heating the steel to redness, and somewhat increased by plunging the steel in cold water.

That magnetism is not only distributed along the surface of a body, but enters it more or less according to the constitution of the body, has been shown by Jamin in his experiments with corrosives. He found that a magnet may possess several layers of magnetism, differing from each other, and he obtained what he termed abnormal magnets, that is, magnets with two north poles, but no south pole, and so on. He took a normal magnet, magnetised its upper layer oppositely, so that he had now a south pole where formerly there was a north pole. The new north pole of his magnet was brought into contact with some acid, which destroyed the upper layer of the magnet. When examined, the magnet showed its original magnetism, that is, south. The remaining pole of the magnet, that is, the south pole, was not put into acid, and it remained south. This magnet, then, had two south poles, but no north pole. Abnormal magnets are obtained through irregular stroking with different poles. The different poles in such a magnet are called consequent or consecutive poles.

Lifting Power of a Magnet.—The lifting power of a magnet may be ascertained by hanging weights from a properly-fitting armature until the armature falls off, then the power of the magnet is equal to the maximum weight held up. If the weights are gradually increased from day to day, the magnet will be found to bear a load much above that which it would have held if the load had been suddenly applied. Small magnets bear greater loads in proportion to their own weights than large ones; and, as a rule, the lifting power of horse-shoe magnets is greater than that of an ordinary bar magnet. The lifting power is also increased by making the area of contact between the armature and the magnet greater. Long thin magnets are more powerful in proportion to their weights than thick ones, hence if any number of thin magnets are placed in a bundle we get a magnet considerably stronger than a solid one of the same weight, or than any of the component magnets. It is, however, less than the sum of the strengths of the separate magnets. Thus, when Jamin placed six equal magnets weighing three kilogrammes, and having a bearing power of 18 kilogrammes, upon each other, the compound magnet had not a bearing power of six times eighteen, or 108 kilogrammes, but only of 64 kilogrammes. On taking it to pieces, each of the component magnets was then found to have only a bearing power of from 9 to 10 kilogrammes. Jamin, by arranging the magnets in this manner, produced the compound magnet which bears his name, a drawing of one being shown in Fig. 13. It consists of steel bands, whose ends are kept in position by the brass cap shown in the figure. The compound magnet, or, as it is sometimes called, the magnetic battery, represented

in Fig. 14, has the components arranged to diminish the influence which the poles of the steel bands have upon each other. They are made of unequal lengths, so that their poles do not fall together.

Magnetic Influence at a Distance. The Torsion Balance.— We can consider experimentally the force of attraction or repulsion between two magnetic poles only when the magnets employed are at a short distance from each other. Under these conditions it is observed that the following law is true, namely, the force exerted by one magnetic pole on another in its neighbour-

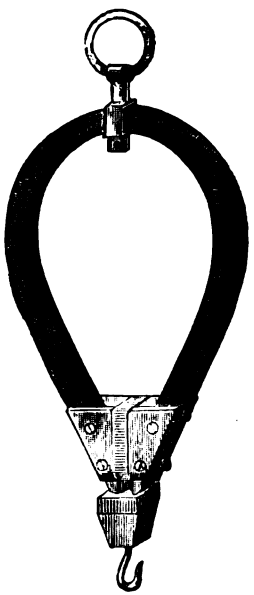


Fig. 13.—Jamin's Compound Magnet.

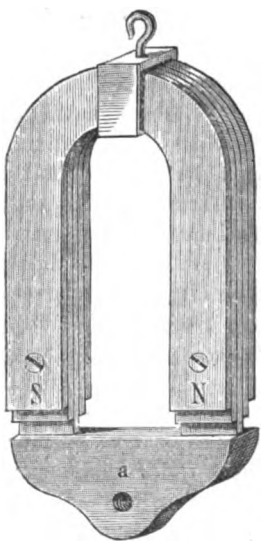


Fig. 14.—Magnetic Battery.

hood, is inversely proportional to the square of the distance between the poles. This is known as the law of inverse squares, and it may be experimentally proved by means of Coulomb's torsion balance (Fig. 15).

This instrument consists essentially of a silver wire *f f*, by which the magnet *n s* is suspended, the torsion of which is measured. This wire is attached to a top called the torsion head, which moves upon a graduated circle *S*, on which the angle of torsion is read by means of the index *i*. The knob *k* is employed to adjust this circle and the magnet *n s*. A second graduated circle T T is also engraved on the larger glass cylinder, to give the angle through which the magnet *n s* moves. The second magnet N S is introduced through a hole in the glass plate, its lower pole N being on a level with the magnet *n s*. When a wire is twisted, the force with which it tends to untwist is proportional to the amount of twist, hence the force required to twist *x* degrees is *x* times the

force required to twist one degree. In other words, the force of torsion is proportional to the angle of torsion. If θ be the measure of the angle of torsion, and F the force, then F = , where a is a constant depending on the size and qualities of the wire and the mode of measuring the angle.

In order to prove the above law, adjust the magnet *n s* by means of *k*, until it lies in the magnetic meridian, so that the wire *f f* by which the magnet is suspended shall have no torsion of any kind. Having done this, ascertain what force of torsion is necessary to move the suspended magnet one degree out of the magnetic meridian when not influenced by the magnet N S. As an example, suppose it requires 9° of torsion to produce a deflection of the magnet of 1°, then a force producing x degrees of deflection will be equivalent to $9x$ degrees of torsion. Having brought the magnet *n s* into the magnetic meridian again, introduce the magnet N S, the north-seeking pole of which will cause *n* to move in the direction T T. The wire will thus become twisted, and the magnet will take up some fixed position where the force of torsion is equal to the force of repulsion exerted between the two poles. Then the force of repulsion is usually the sum of three terms. It equals the number of degrees through which the magnet is deflected × 9.

+ the number of degrees of torsion due to the twist by the magnet.

+ the number of degrees of torsion due to the turn of the torsion head.

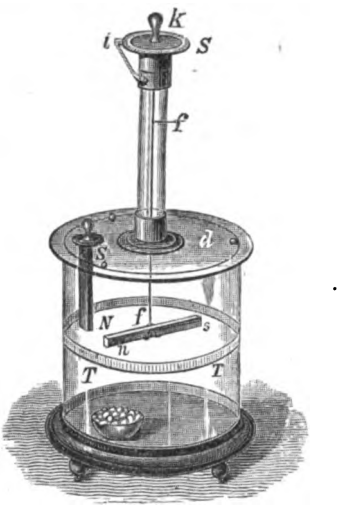


Fig. 15.—Magnetic Torsion Balance.

Suppose this equilibrium occurs when *n* is repelled through 16°, then the force exerted on the pole corresponds to 16×9+16+0 or 160°. By turning *k*, the pole *n* may be brought nearer the fixed pole N; for instance, let *k* be turned till the distance is 8°. Let us suppose that it requires $1\frac{1}{2}$ complete turns of the torsion head to reduce the deflection from 16° to 8°, then the force of repulsion = $8\times9+8+1\frac{1}{2}$ of 360° = 72+8+540 = 620°. This, we see, is nearly four times the former, but the distance is now only half what it was before; hence it is evident, as previously stated, that the repulsive force between two magnets is inversely proportional to the square of the distance. Similar experiments may be carried out at other distances, and with various strengths of the magnetic poles.

Proceeding in this manner, and also varying the strength of the poles, Coulomb proved the following fundamental law of magnetism, which includes that of the inverse squares already given:

The force exerted between two magnetic poles is proportional to the strength of the poles, and inversely proportional to the square of the distance between them.

Thus, if m and m_1 be the strengths of the poles, and d the distance they are apart, then the force f exerted between them is

$$f = \frac{m m_1}{d^2}.$$

If we make f and d unity, the product $m m_1$ must also be unity, and it follows that *the unit magnetic pole is that which repels a similar and equal pole at unit distance with unit force.*

This unit is defined in the centimetre-gramme-second or C. G. S. system, which is the system of fundamental units employed in scientific work, as that *pole which repels a similar and equal pole at the distance of one centimetre with the force of one dyne*, the dyne being that force which causes a gramme of mass to move with the velocity of a centimetre per second at the end of a second.

The Magnetic Field.—We have noticed that a magnet exerts a certain influence on pieces of iron and steel which lie in its neighbourhood. The pole of another magnet also experiences a force varying with its distance from the magnet. We have also seen that iron filings form themselves into certain curves within this region, which are termed lines of force. The region through which a magnet exerts this magnetic influence, or force, is termed a *magnetic field.* The force which a magnetic pole experiences at a point in the magnetic field is determined by the *intensity of the field* at that point, and its direction is the *direction of the lines of force.* The latter is determined by the direction in which a free pole would move. The *intensity of the field at any point is measured by the force exerted on a unit pole placed at that point*, and the *unit intensity is that which exerts the force of a dyne* on a unit magnetic pole.* If f be the force which a pole of strength m experiences at a point where the intensity of field is H, then

$$f = mH.$$

Intensity of Field shown by Lines of Force.—If we carry a small magnetic needle about a pole of a magnet, and draw lines to which it will always be a tangent, we obtain lines which converge to the poles. (*See* Fig. 8.) Suppose these lines drawn, not in one plane only, but in solid space. Now imagine a small ring moved in the neighbourhood of the pole. The number of lines that pass through the ring will vary inversely as the square of its distance from the pole. But this is the law of force. Hence this number may be taken to measure the force at any point. Since the lines of force may be drawn to pass through every part of the magnetic field, the intensity of the field at a point may be measured by the number of lines of force which pass through a unit area placed perpendicular to the direction of the lines of force at that point. A *uniform magnetic field* will therefore be one in which the intensity of the field at every point determined in this manner is the same; in other words, the field is

* See Appendix to Part I.

uniform when the lines of force are parallel. Thus a small field at a considerable distance from a magnet will be fairly uniform, hence the magnetic field due to the earth in a room free from the presence of magnets will be practically uniform, and the direction of the lines of force will be that of the dipping needle placed in the direction indicated by the declination needle.

The Magnetic Moment of a Magnet.—It is impossible to have a single magnetic pole existing independent from one of opposite character; hence it becomes necessary to determine the action produced on these combined poles. The tendency of the force to turn an ordinary bar magnet suspended in a magnetic field may be determined by considering the action on one of its poles, and since the action on the other tends to turn the magnet in the same direction we combine the two by doubling the first. Thus in a uniform field two equal opposite and parallel forces act on the poles of a bar magnet, tending to turn it on its axis and set it in the direction of the lines of force. The pair of forces acting in this manner are in mechanics termed a *couple.* In a field the intensity of which is H, the pole of a magnet of strength m is acted on by a force equal to the product $H\ m$, and if the distance between the poles be l, then the action of the couple on the magnet is

$$c = m\ l\ H.$$

The product $m\ l$ is termed the *magnetic moment* of the magnet. It is evident, from the above formula, that the magnetic moment of a magnet may be considered as defined by the couple acting on a magnet placed perpendicular to the lines of force in a field of unit intensity.

The Intensity of Magnetisation.—By magnetic intensity is meant that power which is necessary to separate the two kinds of magnetism, or rather, to determine the molecules in the substance in the direction or position which constitute them a magnet; and the force required to do this determines the power of the magnet. As we do not know the nature of magnetism, we are not able to measure its intensity directly. We measure it by one of its effects, namely, the tendency of the magnet to take up a fixed position relatively to the earth. This tendency not only depends on the earth's magnetism, but on the strength or intensity of the magnet's magnetism; the greater the intensity in the needle the sooner will it adjust itself to its position. For this force of adjustment a unit has been proposed by Gauss, who also constructed an instrument which showed in what time adjustment took place. This instrument is known as a magnetometer.

Terrestrial Magnetism.—The earth itself has been shown to be a large magnet, in consequence of which a magnetic needle adjusts itself in a direction north and south. The influence the earth has over the magnetic needle must be the same as that of a large magnet over a small one. A large magnet would cause the magnetic needle to place itself with its axis along the lines of force, and the earth does the same. The lines of force in this case are termed magnetic meridians, and the magnetic needle sets itself along these meridians.

Since the magnetic poles do not correspond with those of the earth, it follows that the magnetic meridians will not coincide with the geographical meridians. The inclination of the magnetic to the geographical meridian at any place is what we have termed the declination.

As the distribution of magnetism is very irregular along the surface of the earth, the declination must vary from place to place. This magnetic declination has been accurately measured at different places, and from these results charts have been prepared, showing the declination throughout the world.

We have already shown that besides the form of needle termed the declination needle, there is another termed the Inclination, or dipping needle, which we have described. The angle made by the direction of the needle and the horizontal plane is called the *inclination*, or *angle of dip*. It has been ascertained that the inclination or dip varies from place to place, and accurate measurements of the inclination have been made at various positions on the earth ; and from these partial observations charts have been drawn showing the inclination throughout the world. The maximum inclination occurs at the magnetic poles, where the needle is vertical, and at about equal distances from these poles the angle of inclination is zero.

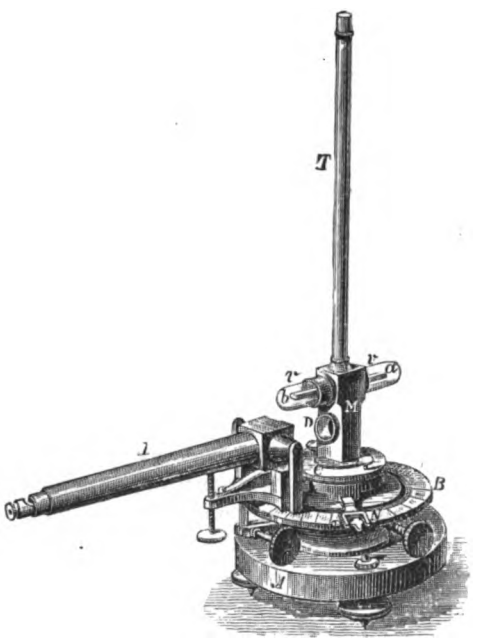


Fig. 16.—Lamont's Reflecting Declinometer.

In the northern hemisphere generally the inclination needle has its north-seeking pole dipping downwards, and in the southern hemisphere its south-seeking pole dipping downwards. It has been already stated that the magnetic north pole of the earth must have opposite magnetism to that of the north-seeking end of the magnetic needle.

A knowledge of the magnetic condition of the earth enables us to examine the magnetic conditions of other bodies. To determine the magnetic condition of the earth at any place, we have to measure the direction and intensity of the magnetic force at that place ; the direction we get by means of the declination and inclination needles, the total intensity by calculation. To determine the declination at different places, Lamont devised an instrument represented in Fig. 16. It consists of a graduated disc B moving on the base A, through the centre of which passes a pivot terminating in a third disc, to which the telescope

L as well as the diametrically opposite verniers are attached. The brass cover M terminates in the tube T, from the upper end of which the magnet *a b* is

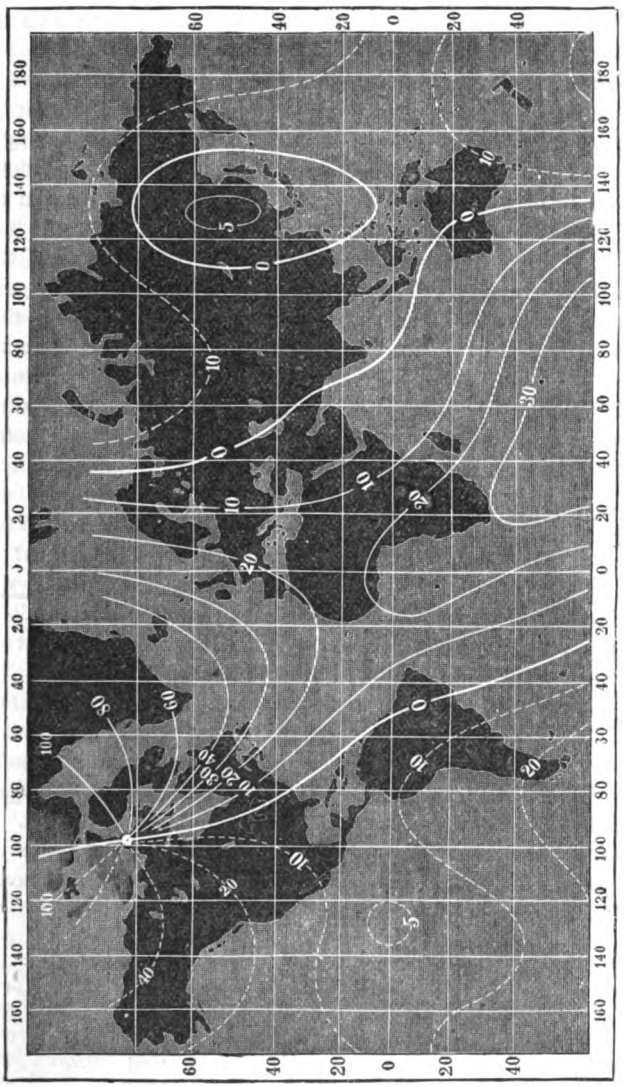


Fig. 17.—Declination Chart.

suspended by means of a silk thread. D is an opening to allow of the rays of light from a little mirror being reflected along the telescope L. This mirror S rigidly attached to the magnet *a b*, being capable of turning with it and thus indicating its deflection. A glass tube *v v* surrounds the magnet *a b*, to protect

it from dust and currents of air, etc. In order to arrange the axis of the telescope perpendicular to the plane of the mirror at D, the telescope, instead of the usual spider threads, is provided with a mirror, upon which a cross has been scratched. When this cross is seen in the reflection the axis of the telescope is perpendicular to the mirror.

Variation of Declination.—Observations made with this and similar instruments show that the declination not only changes for different places, but also that it varies at different times at the same place. Places having the same declination at the same time may be connected together by certain definite lines, termed *isogones*, or *isogonic lines*. The isogonic lines, of which the declination is zero, are called *agones*. These lines are represented in Fig. 17.

The changes that occur at different times are of four kinds, three being periodic and one irregular. The variations of declination which extend over long periods of time are termed *secular* variations. Besides these, there are also annual and daily variations, the whole change being completed in the year or day respectively. Besides the variations that resemble oscillations and recur regularly there are changes of the nature of disturbances These irregular variations, as a rule, appear together with the aurora borealis, and will be again referred to when we come to consider atmospheric electricity.

From the declination chart we see that one portion of the world has western declination, the other part eastern. The two parts are separated from each other by the agones, or neutral lines, of which up to the present two distinct portions are known. One line of no declination runs from Hudson's Bay across the eastern portion of North America, the Atlantic Ocean, the West Indies, the eastern portion of South America, then back again to the ocean. The second goes over Asiatic Russia (Lat. 40° and 50° east), the Caspian Sea, the eastern portion of Arabia, and through the western half of Australia. It is suspected that both parts form closed curves. All the isogones intersect each other at two points, which are near the geographical poles, and are called magnetic poles, and lie near Bœotia Felix and the volcanoes Erebus and Terror. Tables of secular variation show us that until the seventeenth century the declination for Europe was eastern, and then changed into western. The following tables give the declination observed at Paris and London:

PARIS.			LONDON.		
In the year 1580	...	11° 30′ *east.*	In the year 1580	...	11° *east.*
,, 1618	...	8° 00′ ,,	,, 1622	...	6° ,,
,, 1663	...	0° 00′ ,,	,, 1657	...	0 *due north.*
,, 1700	...	8° 10′ *west.*	,, 1665	...	1° 22′ *west.*
,, 1805	...	22° 5′ ,,	,, 1700	...	9° *west.*
,, 1818	...	22° 22′ ,,	,, 1800	...	24° 7′ *west.*
,, 1828	...	22° 6′ ,,	,, 1818	...	24° 41′ ,,
,, 1849	...	20° 34′ ,,	,, 1850	...	22° 30′ ,,
,, 1880	...	18° 20′ ,,	,, 1867	...	20° 50′ ,,
			,, 1880	...	18° 35′ ,,

At present the declination for Europe is west, being again on a decrease. Ganes and Weber collected observations made during twenty-four hours, for four fixed days of the year, at different places on the globe, to determine the daily variations in the earth's magnetism.

They found that the declination in Europe is a minimum in the morning, maximum shortly after mid-day, and then decreases until evening. The maximum difference, although not the same for all seasons, is only nine minutes.

Inclination, as we have previously mentioned, is determined by means of the inclination, or dipping needle, which must be either freely suspended, or allowed to turn on a horizontal axis passing through the centre of gravity of the needle, friction in the bearings being as much as possible avoided. Fig. 18 shows a simple arrangement of the inclination needle. It consists of the dipping needle *a b*, capable of moving about the horizontal axis at *m*, the pivots of which are arranged to move in their bearings with as little friction as possible. On the vertical graduated circle K_2 is measured the inclination or dip. The graduated circle k_1 and vernier *n* are employed to arrange the needle and circle K_2 in the magnetic meridian, the whole instrument being carefully levelled by means of the level *w* and the screws *s s*. The instruments employed at the Kew Observatory are more exact and delicate than the one here described, the fractions of degrees being read off by means of microscopes which are attached to the same rods as the verniers.*

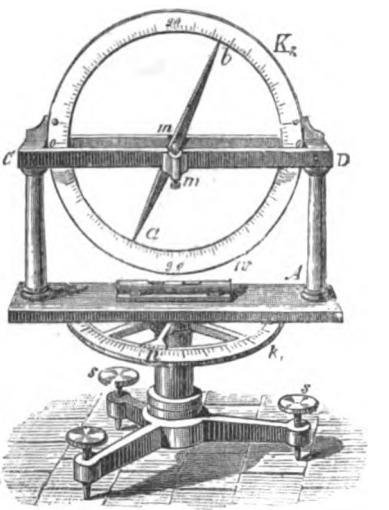


Fig. 18.—Inclinometer, or Dipping Needle.

Variation of Inclination.—Like declination, inclination varies for place and time; here, too, places may be found that have the same inclination. The lines which join these places are called isoclinic lines, and the isoclinic line of which the inclination is o is called the magnetic equator, or aclinic line; from the magnetic equator to the magnetic poles the inclination varies from 0° to 90°. At the magnetic equator the inclination needle would take up a horizontal position; in the northern hemisphere its north pole points downwards; in the southern hemisphere its south pole points downwards, and at the

* At the Observatory at Greenwich the declination needle is made to record its own movements every day. The magnet carries a small mirror on which a beam of light falls in a dark room The light is reflected on to photographic paper ruled for hours and minutes, and placed round a cylinder turned by the clock. The dark line traced by the spot of light is a permanent record of the movements of the magnet.

magnetic poles it assumes a vertical position. The magnetic equator does not run parallel with the geographical equator, but cuts it at several places, as shown in the chart (Fig. 19).

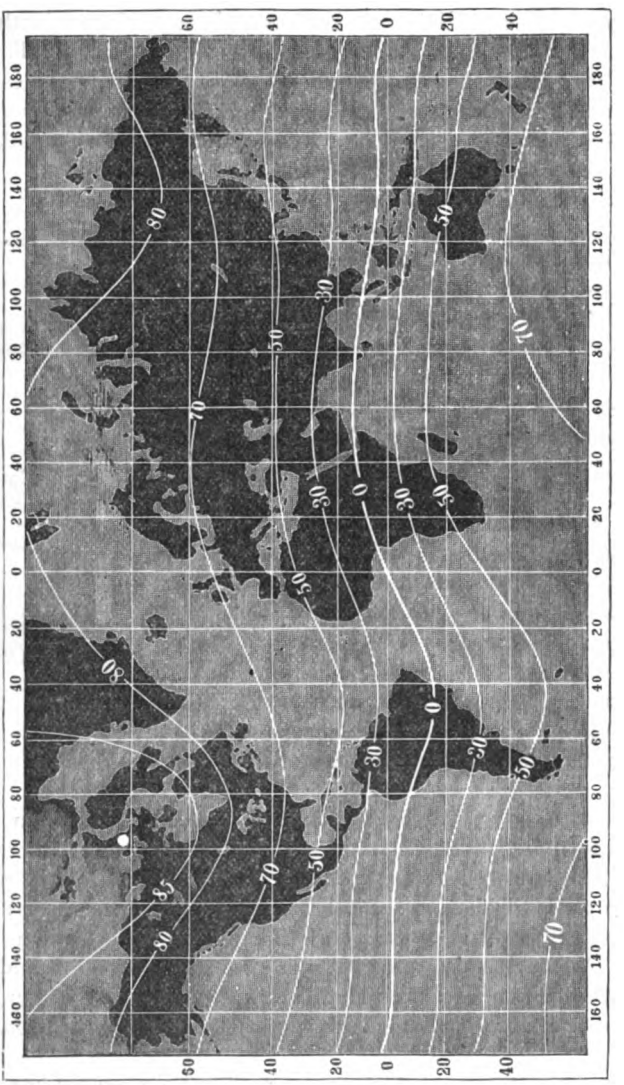


Fig. 19.—Inclination Chart.

The following figures show the variations of the inclination observed at Paris and London :

PARIS.			LONDON.		
In the year	1661	75° 00′	In the year	1576	71° 50′
,,	1758	72° 15′	,,	1676	73° 30′
,,	1805	69° 12′	,,	1720	74° 42′
,,	1820	68° 20′	,,	1780	72° 8′
,,	1835	67° 24′	,,	1800	70° 35′
,,	1851	68° 35′	,,	1830	69° 30′
			,,	1867	68° 4′
			,,	1870	68°
			,,	1880	67° 36′

It is difficult to determine whether the variations of dip are periodical; since 1835 the dip for Paris seems to be increasing, whilst for London it shows a steady decrease.

Intensity of Terrestrial Magnetism.—To determine the earth's magnetism, we have not only to know declination and dip, but intensity also; which is obtained by taking into account the directive force of the earth. Several methods are known for obtaining this result. The instrument Gauss used for the purpose is shown in Fig. 20. The magnet is held by the frame *s s*, which is suspended by means of wires running over pulleys, and carrying a graduated scale K. From the centre of the scale rises a tube, to which is attached a vernier, and the mirror *S*. The mirror serves the purpose of reflecting the divisions of a scale under a telescope not far distant. The first thing to be done is to regulate the instrument and bring the mirror into such a position that when the suspension wires lie in the same plane then the mirror is at right angles to this plane. For this purpose a bar of copper of the same weight and shape as the magnet is placed in the frame. The apparatus assumes the position of equilibrium, and the two parts of the wire are then in the same plane. The mirrors and telescope are then turned until the middle of the scale is seen by the reflections coinciding with the vertical spider-thread in the telescope. The scale as well as the mirror is then perpendicular to the plane, which contains both the wires and optic axis of the telescope.

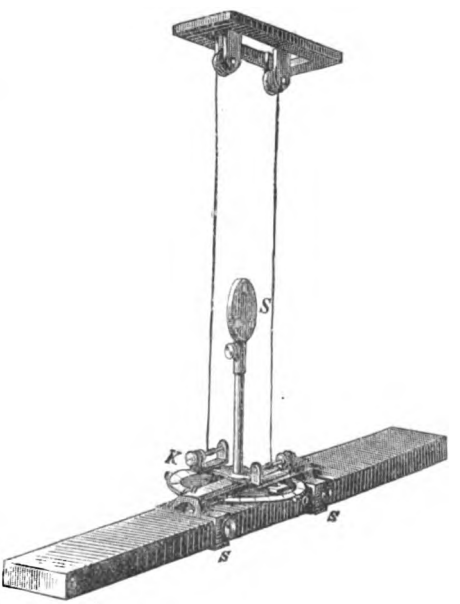


Fig. 20.—The Bifilar Magnetometer.

We now replace the bar of copper by the magnet. The forces which act on the magnet are its weight, the couple arising from terrestrial magnetism, and the

tensions of the wires. Each of these tensions may be regarded as made up of two components, one being vertical, and the other horizontal. The vertical components balance the weight, and the horizontal components form a couple (or two equal and opposite forces). The distance between the wires is so regulated that this couple is greater than the couple due to the earth's magnetism. We now make three observations, and count the number of the oscillations of the magnet in three positions.

1. Place the magnet and frame in the direction of the magnetic meridian, the north-seeking end being towards the north. Adjust the apparatus, slightly disturb the magnet, and count the oscillations. Let the number per minute be N, then the sum of two couples is proportional to N^2.

2. Reverse the magnet so that the north-seeking end is towards the south. Let n be the number of oscillations per minute. Then the difference of the couples is proportional to N^2.

3. In the third position the upper part of the suspension apparatus is turned round till the axis of the magnet is perpendicular to the magnetic meridian. When there is equilibrium in this case we can calculate the value of the couple due to the tensions, and this couple then balances the couple due to terrestrial magnetism.

If H be the product of the earth's horizontal magnetic force and the moment of the magnet,

F the couple due to the tensions,

1 gives $F + H = K N^2$ where K is a constant.

2 gives $F - H = K n^2$.

3 gives $F \sin \alpha = H$, where α is the angle between the magnet and suspension head.

From 1 and 2 $\frac{F}{H} = \frac{N^2 + n^2}{N^2 - n^2}$ which should agree with 3.

The transverse position, therefore, is suitable for detecting and comparing changes in H.

Another method more frequently used in English laboratories makes use of the unifilar declinometer. This method enables us (1) to compare the magnetic moments of a magnet under different conditions of magnetisation; (2) to compare the strengths of two magnetic fields; or (3) to measure the moment of the magnet and the strength of the field in which it is, that is to say, the earth's horizontal force. For these experiments we require to know a quantity termed the moment of inertia of the magnet. Let K be this quantity. Let M be the magnetic moment of the magnet, H the horizontal component of the earth's magnetic force, and n the number of oscillations per second, when the magnet is suspended in the magnetic meridian, and then slightly disturbed. It is proved by mathematical reasoning that

$$M H = 2\pi K n^2.$$

To separate M and H another equation is also required. This is obtained by placing the magnet with its centre at a distance r from the centre of a suspended

magnetic needle, and in the same magnetic meridian, and observing the deflection, α. If our magnet be at right angles to the line of centre, or, as it is called, "broadside on," then by equating the effects of the magnet and the earth when there is equilibrium, we obtain

$$M = H r^3 \tan \alpha.$$

In these two equations α and n are known from the observations, and K is calculated by measurement. In the case of a bar magnet of mass m, length l, and breadth b, the axis of oscillation being perpendicular to the side $l b$.

$$K = \frac{m}{12} (r^2 + b^2).$$

It follows that now both M and H can be found from the two equations.

Example.—The magnet weighed 67 grammes, and its length was 9·75 centimetres, and its breadth ·503 centimetre. The time of oscillation when the magnet was suspended by a single thread was 4·4 seconds, and when it was used broadside on to deflect another magnet, at a distance of 20 centimetres, it gave an angle whose tangent was found from the tables to be ·322. The third equation gives for K 245, and the others give us M H = 79·54, and M ÷ H = 2568. Hence, M = 452, and H = ·176.

The force here referred to was simply a horizontal force. The total force of the earth's magnetism on either pole of the needle has the effect of two forces, one pulling the needle into the magnetic meridian, which we may call the horizontal part (or component), and the other pulling one end of the needle down. This latter may be called the vertical component. We may easily determine the total force when we know the horizontal component and the angle of dip. We have but to choose a scale and to construct a triangle thus: Draw A B, a horizontal line, to represent on the chosen scale the horizontal force; next draw B C, making the angle A B C equal to the angle of dip; then draw A C perpendicular to A B, and meeting B C in C. Then on the chosen scale A C represents the vertical component V, A B the horizontal component H, and B C the total force T.

$$T = H \div \cos A B C, \text{ and } T^2 = H^2 + V^2.$$

The observations yet made seem to point to a steady increase of intensity. At Munich (Germany), it has been as follows:

1853	...	1·9578
1857	...	1·9706
1862	..	1·9821
1867	...	1·9973
1871	...	2·0093

The horizontal component of the earth's magnetic force at Kew (England),

has been carefully calculated in C. G. S. units year by year since 1860. It was in

1860	..	·1755
1862	...	·1760
1864	...	·1765
1866	...	·1770
1868	..	·1775
1870	..	·1779
1872	...	·1785
1874	...	·1790
. .	. . . .	. .
1884	...	·1819

The total force in 1884 at Kew was ·472 in C. G. S. units.

Intensity also has daily variations: increasing from morning till evening, and decreasing during night.

STATICAL ELECTRICITY.

Electrical Attraction and Repulsion.—If we rub a large glass rod with a silk pad, we observe that it will attract light bodies, then after contact repel them. During the process we may notice a peculiar noise, and if the experiment be carried out in the dark, we may further notice sparks passing between the rod and the rubber, and also that the rod becomes luminous. If we suspend a pith-ball by means of a silk thread, on bringing the rubbed rod near the pith-ball it will move towards the rod, touch it, and then be repelled. If the glass rod be again brought near the pith-ball, it will move away from the glass rod, and continue to be repelled until it has been touched by some other body. From this and similar experiments we conclude that by means of friction certain bodies may be made to assume properties they did not before possess. That which gives bodies these properties we call electricity, and we speak of the bodies exhibiting them as being electrified.

In order to ascertain whether electricity is communicated by electrified bodies to non-electrified bodies when brought into contact, let us suspend two pith-balls from the same point of support by threads of uniform silk, and touch the pith-balls with the rubbed glass rod. The balls fly from the rod and also from one another. On bringing near them a third pith-ball or any other light body, we find that though they repel one another they are attracted by the light body, showing that they have become electrified by contact with the rubbed glass rod. From this we conclude that an unelectrified body may be electrified by contact with an electrified body, and also that there is repulsion after contact. There is mutual repulsion between two electrified bodies, but there is attraction between a single electrified body and one that is unelectrified. Since electricity may be imparted from one body to another in the manner here described, we may speak of a body as being charged with electricity, or as having a certain charge, though the only evidence we have of a body being charged is

the force it exerts on other bodies, whether that force be one of repulsion or attraction. This property or behaviour of electrified bodies enables us to examine their electrical condition.

Gold-Leaf Electroscope.—The simplest apparatus for this purpose is the gold-leaf electroscope, which, in its most elementary form, consists of two gold leaves hung side by side within a glass vessel from a metal wire attached to a metal plate or ball on the exterior of the vessel, as shown in Fig. 21. If we touch the metal knob of the instrument with a rubbed glass rod, the electricity of the glass rod reaches the gold leaves, causing them to diverge, as shown in the figure. We may further observe that the more strongly the rod is electrified the greater is the divergence of the leaves.

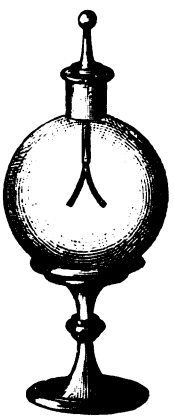


Fig. 21.—Gold-leaf Electroscope.

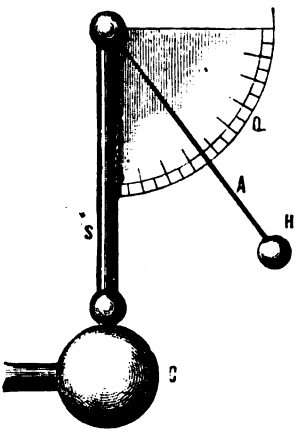


Fig. 22.—Quadrant Electroscope.

Henley's Quadrant Electroscope.—Another form of electroscope is that known as Henley's quadrant electroscope, shown in Fig. 22, which is used to indicate the charge on the prime conductor of an electrical machine. It consists of a metal rod S, having brass balls at both ends. A thinner rod A, terminating in a pith-ball H, is hinged to the upper ball on S, thus allowing of movement over the scale Q. To measure the charge of the conductor C, the instrument is placed on the conductor, the rod A H lying close to S when the conductor has no charge. On electrifying the conductor C, the electricity flows to the electroscope through the lower ball of S, which repels the pith-ball H. The proportionate amount of electricity contained by the conductor is indicated by the angle shown on the scale Q.

Behrens' Electroscope. — It would be almost impossible to indicate the presence of very small quantities of electricity with the gold-leaf electroscope just described, hence more sensitive instruments must be employed. We will describe an electroscope invented by Behrens, and modified by Riess. It is

shown in Fig. 23, the new feature being a Zamboni pile, though the instrument is only a delicate form of the gold-leaf electroscope. It consists of a single gold leaf hanging between two symmetrically placed discs *k z*, which are maintained at different electrical conditions, or (as we shall subsequently learn to describe them) at different potentials, one positive and the other negative, produced by the dry pile, or battery K Z. Sir William Thomson calls electroscopes of this class heterostatic, because they take advantage of an independent electrification to test the given electrification.

None of these instruments accurately measure electricity; they only indicate the electrical conditions of bodies. Apparatus which enable us to make exact measurements of the charges of electricity on bodies are termed *electrometers*, not *electroscopes*, and will be described farther on. The latter simply indicate the presence of electricity; the former do more than this: they measure the quantity.

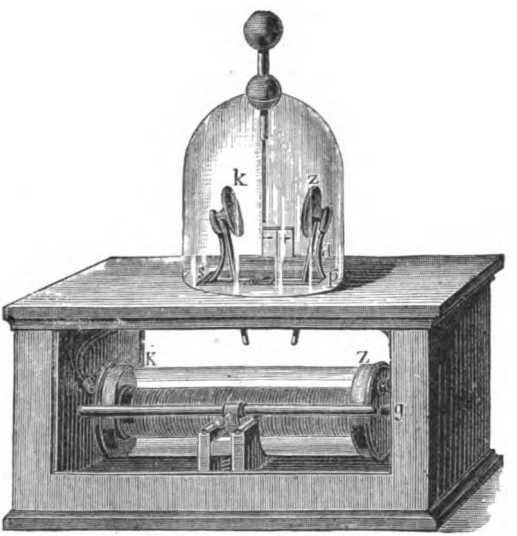


Fig. 23 —Behrens' Electroscope.

Two kinds of Electrification.—If we rub a glass rod with a piece of leather, and touch the knob of the gold-leaf electroscope, the leaves diverge; on rubbing the glass rod still more, and touching the knob of the electroscope, the divergence of the leaves will be increased; but if, instead of again using the glass, we touch the knob with a rubbed rod of sealing-wax, the leaves collapse. If we reverse the order, touching the knob with the rubbed sealing-wax first, the leaves diverge, and then collapse when the knob is touched by the rubbed glass rod. This experiment shows that although both the glass and the sealing-wax rods become electrified by rubbing, the electrical conditions of the two bodies are opposite in character. When one makes the gold leaves diverge, the other makes them collapse. We distinguish, therefore, between two kinds of electricity; viz., that of the rubbed sealing-wax, which we term *resinous*, and that of the rubbed glass, which we term *vitreous*.

Further experiments show, however, that the nature of the electrification of bodies depends not only upon the bodies rubbed, but also upon the rubber.

The electrical condition of a body is not sufficiently indicated by either of these significations, and it was therefore agreed that the one kind of electrification should be termed *positive*, and the other *negative*: glass rubbed with amalgamated

leather was to represent the former, resin rubbed with wool the latter. Therefore, positively electrified bodies are all those bodies that exhibit the same properties as a glass rod rubbed with amalgamated leather, and negatively electrified bodies all those which exhibit properties opposite to the above named. The phenomena observed, concisely stated, come to this: 1. There are two kinds of electricity, positive and negative; 2. Bodies charged with the same kind of electricity repel each other, while bodies charged with opposite electricities attract each other; 3. Equal quantities of the opposite kinds of electricity united in a body neutralise each other.

By means of the instruments already described, and employing these facts, we are enabled to examine the electrical condition of bodies, and ascertain which kind of electricity a body has. The method adopted with the gold-leaf electroscope is the following: The instrument is first charged, say, positively, being touched with a glass rod rubbed with leather, which causes the leaves to diverge, then the knob is touched with the body under examination; if the leaves diverge still further the body is charged with positive electricity, if the leaves partly or entirely collapse, the body is charged with negative electricity. Care should be taken to ascertain whether the body is at all electrified, as the divergence of the gold leaves is lessened when a non-electrified body touches the knob, because some of the electricity of the gold leaves has been imparted to the body.

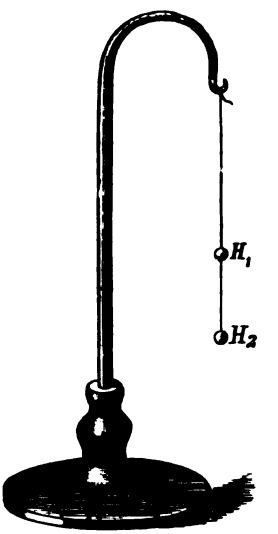


Fig. 24.—Electric Pendulum.

Conductors and Insulators.—If we suspend a pith-ball H_1 by means of a silk thread, and a second H_2 by means of a metal wire from the former, and touch H_1 with a rubbed glass rod, H_1 becomes positively electrified, and is consequently repelled by the glass rod; and H_2 is also repelled, although not touched by the rod. Further, H_2 is attracted by a rod of sealing-wax, and is also able to attract light bodies. No electricity has been imparted to H_2 directly by contact with the glass rod, yet it shows the same properties as H_1; hence it follows that electricity from H_1 must have passed to H_2, or, in other words, that the metal wire *conducted* the electricity from H_1 to H_2. If we suspend H_2 from H_1 by a silk thread instead of a metal wire, H_2 will exhibit no sign of electrification, showing that the silk does not conduct electricity.

Again, if we touch the knob of a charged electroscope with an unelectrified sealing-wax rod, the divergence of the leaves is lessened; but on examining the rod of sealing-wax by Behrens' electroscope, we find it electrified only at the place where contact was made with the electroscope. Other substances, such as metals, become electrified all over the surface when only touched at one point. These facts show that we have to distinguish between two classes of bodies, in the

first of which the electricity rapidly spreads over the surface, and in the second of which the electricity only spreads over the body at a very slow rate. The former class of bodies are termed *conductors* and the latter *non-conductors*, or *insulators*. If the knob of a charged electroscope be touched by the hand, the leaves collapse at once, the electricity being conducted by the human body to the earth, thus becoming distributed over a very large surface. In order to find whether a substance is a good conductor of electricity or not, take the substance to be examined, and touch the knob of the electroscope with it; if the leaves collapse immediately, the substance conducts electricity well. It may be proved by touching a second unelectrified electroscope, that the substance retains no signs of electrification, simply because the electricity has passed from it through the human body, and thence to the earth. The time which the gold leaves take to collapse gives us a method of roughly ascertaining the relative conducting powers of substances. With metals this collapse takes place immediately, with resins more slowly, and with dry wood more slowly still.

We can draw no strict line of division between conducting and non-conducting bodies, since all substances offer a certain resistance to the passage of electricity, and there are none that absolutely resist it. In the following list, due to Riess, the names of the substances are arranged so that each conducts better than the next. They are also classed as conductors, partial conductors, and insulators.

CONDUCTORS.

Metals.	Sea-water.	Parts of animals having still life.
Charcoal.	Fresh-water.	Soluble salts.
Graphite.	Rain-water.	Linen.
Acids.	Snow.	Cotton.
Salt solutions.	Growing vegetables	

PARTIAL CONDUCTORS.

Alcohol.	Dry Wood.	Straw.
Ether.	Marble.	Ice at 0° C.
Flower of sulphur.	Paper.	

INSULATORS.

Dry metal oxides.	Porcelain.	Precious stones.
Oils (fatty).	Dried vegetables.	Mica (biaxed).
Ashes.	Leather.	Glass.
Ice at −25° C.	Parchment.	Wax.
Phosphorus.	Dry paper.	Sulphur.
Lime.	Feathers.	Resin.
Chalk.	Hair.	Amber.
Caoutchouc.	Wool.	Shellac.
Camphor.	Dyed silk.	
Oils (ethereal).	Silk.	

Here, then, we have an explanation of the reason why in the earliest times, and even as recently as the time of Gilbert, many substances were considered

incapable of electrification by rubbing. Bad conductors, such as amber, could be held in the hand without the electricity generated by rubbing being conducted to the earth. Metals, on the contrary, conducted the electricity produced by means of the hand to the earth. In order to electrify metals, or any other conductors, therefore, we must support them in some manner by means of an insulator. If they be held by glass handles, or suspended by a silk thread, they may be electrified by rubbing.

Gases are bad conductors of electricity; if it had been otherwise we should never have become acquainted with electricity, as it would have been conducted away by the air as fast as it was generated. The vacuum also does not conduct electricity, but moist air becomes a partial conductor. Moist air, also, will spoil the insulation of non-conducting supports. All bodies are more or less hygroscopic, and the moisture condensed on their surfaces thus turns the best insulators into conductors. Change of temperature also influences conductivity; red-hot glass and molten resin, for instance, becoming good conductors.

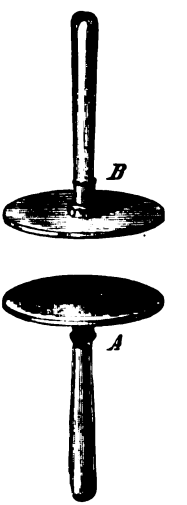


Fig. 25.—Insulated Conductors for Frictional Electricity.

In order, then, to ascertain whether a body can be electrified or not, it is not sufficient merely to take that body in the hand and rub it; it should be carefully insulated first. When such precautions are taken we find that all bodies, without exception, can be electrified. Experiments show that the rubber also becomes electrified. Fig. 25 represents the apparatus for this purpose. A is a glass disc, B a disc covered with amalgamated leather; both being insulated by means of glass handles. If these two plates are rubbed together, each of them becomes electrified, the glass plate positively and the leather negatively. If we change the glass for resin, and cover B with wool instead of leather, and then rub them together, the resin plate becomes negatively electrified and the wool plate positively. From these and similar experiments we learn that: 1. All bodies may be electrified by rubbing; 2. Both bodies are electrified when rubbed, one of them positively and the other negatively. But the same substance may be either positively or negatively electrified by using different rubbers.

The following list is so arranged that any substance in it becomes positively electrified when rubbed by any of the substances taking rank after it:

Catskin.	Wood.	Resins.
Glass.	Sulphur.	Guttapercha
Ivory.	Flannel.	Metals.
Silk.	Cotton.	Guncotton.
Rock crystal.	Shellac.	
The hand.	Caoutchouc.	

Modes of producing Electricity. — *Direct Methods.* With the first method discovered in order of time, namely friction, we may associate other mechanical processes, such as cutting, filing, pressing, etc. etc. For instance, Iceland spar, when pressed with the hand, becomes electrified, and remains so for a considerable time. Electricity may be produced by heating certain crystals. The electricity produced by this method is sometimes called pyro-electricity. A good example of pyro-electricity is tourmaline: it remains unelectrified as long as it has the same temperature as surrounding bodies; but if it be heated or cooled, it shows two different electrical poles, opposite to each other, which are easily tested by means of an electroscope. It is found that the pole which has positive electricity when heated will have negative when cooled. Tourmaline retains its electrical properties when powdered. Another mode of generating electricity occurs in the chemical process of combustion. It has been found that when bodies are slowly consumed by fire they themselves are negatively electrified, whilst the escaping smoke is positively electrified.*

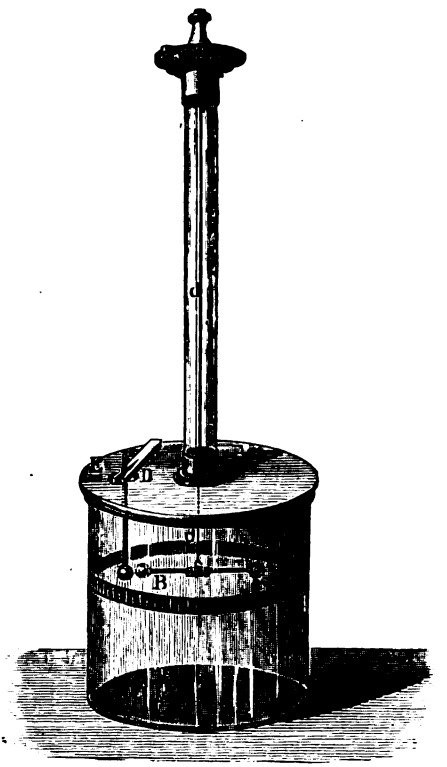


Fig. 26.—Coulomb's Torsion Balance.

Comparison of Two Charges of Electricity.—It has been mentioned that the only evidence of a body's being charged with electricity is afforded by the force it exerts on other bodies. It is evident, therefore, that we must measure quantities of electricity by the relative forces which these quantities exert under similar conditions, and in order to do this we must ascertain the connection between the quantities of electricity and the forces they exert. It has been mentioned, in describing Henley's quadrant electroscope, that the greater the charge of electricity on the balls the larger the angle subtended by the rods, and that this angle increases with the amount of electricity on the conductor. But what relation the angle bears to the charge cannot be determined with so rough an instrument. In order to ascertain accurately the connection between the force exerted between two electrified bodies,

* The experiment was made with a pastil for fumigating.

Coulomb employed his torsion balance (Fig. 26). This instrument has been described in its application to magnetism, as well as the principles on which it depends, and the manner of employing it. Here, however, the suspended magnet is replaced by the balls balanced at the extremities of a glass or shellac rod, as shown at B, and a similar ball attached to the end of a glass or shellac rod inserted at E replaces the fixed magnet. By means of this arrangement Coulomb proved the fundamental law of electricity, namely, that "two small electrified bodies attract or repel each other with forces proportional to the amounts of electricity they contain, and inversely proportional to the square of the distance between them."

If q_1 q_2 be the quantities, d the distance, and F the force then

$$F = \frac{q_1 q_2}{d^2}.$$

Measurement of Electricity.—To measure quantities of electricity absolutely it is necessary to have some unit, and the definition of this unit is furnished from the above-mentioned law by making the two quantities equal, and the force and distance each unity. This unit, defined in terms of the fundamental units now universally adopted in scientific work, is, the quantity of electricity concentrated at a point which is capable of repelling a similar quantity of electricity at a point when placed at the distance of one centimetre with a force of one dyne *, that is to say, with a force which would give the mass of one gramme the velocity of one centimetre per second in one second. As it is impossible to concentrate electricity at a point, we may use two small balls of similar dimensions, the distance of one centimetre being measured from centre to centre.

Gradual Leakage of Electricity.—If we charge the balls of a Coulomb's torsion balance, and observe the angle, we find that when the instrument is left in the same position for some time this angle becomes smaller and smaller. As the force of torsion cannot alter, there must be some waste of the charge. How is this waste to be explained? The balls are surrounded by air, and are fastened to insulators; so that the electricity may escape by the air, or by the insulators, or by both. Experiments have shown that this is really the case. Electrified bodies attract small particles of air, electrify them, and then repel them; in this manner the original quantity of electricity is diminished.

As has been mentioned, there are no perfect insulators; electricity is conducted, though very slowly, through the best insulator. To what extent the electricity will spread over the insulator depends upon the amount of electricity the body itself contains. The amount of electricity on the insulator diminishes with the distance, being densest near the charged body. If there be dust or moisture on the insulator the electricity will be conducted away.

* See Appendix to Part I.

To prevent the condensation of moisture glass insulators are often coated with a thin layer of shellac. There is, however, an objection to this remedy, as particles of dust stick to the shellac, and are not so easily removed. A better method is that adopted by Professors Ayrton and Perry, who place their insulators in glass vessels with strong sulphuric acid, or ɔme other desiccating agent.

ELECTRIFICATON BY STATICAL INDUCTION.

Riess's Induction Apparatus.—The presence of an electrified body is sufficient to produce signs of electricity in a neighbouring conductor. To show this influence of electricity, Riess devised the apparatus represented in Fig. 27. The stand *f* has three movable arms, the middle portion of each consisting of glass. The highest arm holds a brass rod, or hollow cylinder, neatly rounded at its ends, which has pith balls at different places suspended by means of thin metal wires; the middle arm supports the glass plate *d*, and the lowest arm the brass ball *e*. The rod *a b* is in a line with the centre of this brass ball. The three arms are so arranged that all the parts are near to each other, but are not in contact. Immediately the ball *e* is charged, the rod *a b* becomes also electrified. This is manifested by the repulsion of the pith balls. The ball *e* and the rod *a b* do not touch each other, being separated from each other by the glass plate *d*. It is evident, therefore, that *e* influences *a b* through a distance. Electricity, when produced in this manner, is said to have been caused by *induction*. By placing the pith balls at different heights, we may prove that the density of the electricity on *a b* is greatest at its ends. If we move the pith balls along the rod, we find that at a point near the middle of the rod the density is nought. If now we examine the electricity on the two ends of *a b*, we find that the electrical condition of *a* is opposite to that of the brass ball *e*, and the electrical condition of *b* opposite to that of *a*. The point at which there is no sign of electrification is not quite in the middle of rod *a b*, being nearer *a* than *b*. The influenced body retains its charge only so long as the ball *e* is not withdrawn. We can, however, permanently charge *a b* by simply preventing the two electricities from uniting. Let *a b* consist of two parts. Suppose *e* to be positively electrified. On bringing *e*

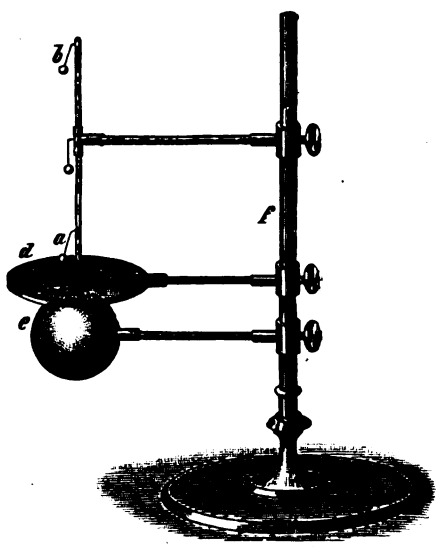


Fig. 27.—Riess's Induction Apparatus.

near *a b* the neutral electricity of the latter will be decomposed, its negative electricity will be found on the lower half, and its positive on the upper part of *a b*. If now the two parts are separated from each other, *e* may be removed also, or discharged, and yet the two parts of *a b* will retain their charges. The parts *a* and *b*, of course, must be well insulated as regards the rest of the apparatus. Negative electricity only is obtained when *a b* is connected for an instant with the earth, the connection being removed before the removal of the influencing charge on *e*. The relation between the charges on the influencing bodies and the influenced conductors may be shown by the following experiment: Two equal brass balls, each insulated, are so placed that they touch each other; a third ball, considerably larger, and charged with positive electricity, is brought near them; the three balls are so arranged that their centres lie in a straight line. The ball nearest the charged one shows negative electricity; the ball farthest from the charged one shows positive electricity. The charge of the near ball is measured by means of the torsion balance, and the ball brought back again to its former position. The large ball now is touched by another equal to it; by doing so, the charge of the inducing ball is diminished to one-half of its original charge. The remaining charge is now allowed to influence the two small balls again, and the near ball is again examined by means of the torsion balance. Allowing for leakage, we now obtain a result which is one-half of the first. From this we may conclude that the quantity of the induced charge is proportional to the quantity of the inducing charge.

Æpinus rubbed the end of an unelectrified glass tube with an electrified one, and found that the electricity at that particular spot was similar to that of the electrified tube; he also found a spot in the glass tube that was oppositely electrified, and a third place similarly electrified. This may serve to show that electrified bodies not only influence conductors, but insulators also. This may also be seen by means of Riess' apparatus (Fig. 27). The brass rod or cylinder *a b* must be replaced by some insulator, for instance, a shellac rod. If the ball *e* is positively electrified, the shellac rod on the near end (that is, the end nearest the ball *e*) will be found to be negatively electrified. The difference between good conductors and good insulators is, however, very marked. Conducting bodies when brought near an electrified body are at once influenced, redistribution taking place at once on the removal of the charged body; with non-conducting bodies both processes take a considerable time.

Theory of Induction.—We will next try to explain the phenomena connected with induction. What has been said already comes to this: An electrified body influences an insulated non-electrified body in such a manner that the latter becomes charged with both kinds of electricity, the electrified body attracting the kind not like its own and repelling that which is like its own. The inducing body loses nothing of its electricity, and the quantities of the induced charges are equal to one another, and are proportional to those of the inducing charges. When the inducing charge is removed to a distance the induced charges re-unite. If, however, the body, while under induction,

be connected with the earth for an instant, the induced charge that is repelled flies to earth; then if the influencing body be removed, the insulated conductor remains charged with a kind opposite to that of the inducing charge.

From the fact that conducting bodies become electrified by merely bringing them near charged bodies, without any loss of electricity by the latter, but appear unelectrified when the charged body is withdrawn, it is evident that both kinds of electricity must have been present in the conductor previous to the induction. They could not, however, be detected before induction, because they neutralised each other. We must conclude, therefore, that every non-electrified body possesses an infinite amount of both positive and negative electricity in all its parts, and in equal quantities. It does not, however, exhibit any signs of electrification while these equal quantities of positive and negative electricity neutralise each other. The generation of electricity by induction is therefore merely a separation of the positive and negative electricities, in consequence of the presence of an electrified body and the attraction of the opposite kind of electricity, and repulsion of the similar kind of electricity to that of the influencing charge. Assume the charged body to have positive electricity. When a non-electrified body is brought near it we have to do with three distinct charges of electricity, the positive charge of the inducing body and the positive and negative induced charges.

By means of these observations it is easy to explain the action between an electrified body and an insulated conductor that is brought into contact with it. Before contact takes place the neutral electricity of the conductor is decomposed by the influence of the electrified body, the original charge attracts that which is opposite to itself, and in its turn is attracted by the opposite induced charge. When the bodies touch, the attracting and opposite charges begin to unite. As they unite, however, the separation of the induced electricities depending on the independent existence of the original charge is lessened. The result is that equal quantities of both original and induced electricity will neutralise each other. If $+ e$ be the original charge, and $- i$ and $+ i$ the induced charges, then half of the $- i$ neutralises half $+ e$, and the remaining half of $- i$ returns to neutralise half of $+ i$. The remaining electricity is then distributed over *both* bodies, and the two bodies, being similarly electrified, will repel each other. The action which took place in the experiment (Fig. 27), when the conductor *a b* was connected with the earth, may also be now explained. The conductor *a b* has at *a* an induced negative charge of electricity, and at *b* an induced positive charge of electricity, since the inducing body is positively electrified. If now we touch *a b* with another conductor, the induced charge of positive electricity at *b* will be repelled as far away as possible, and will spread itself over the distant end. In removing this part of the conductor the positive charge will be removed with it, becoming distributed over its surface according to certain definite laws which will be explained further on. If now this end be connected with a large conductor (the earth, for instance), then the positive free charge will spread itself over the large surface, the electrical condition of which, in consequence of its

size, will not be practically affected. The remaining electricity will of course be negative.

Theory of Potential.—It has been pointed out that the relative electrical condition of two bodies may be such that a discharge of electricity takes place between them when they are brought into contact or are connected by a wire. We have now to give a name to this relative electrical condition, and to make certain explanations respecting it. We shall be assisted in the explanations by an analogy, which we shall frequently make use of for a similar purpose. The analogy is that of two bodies in different electrical conditions to two water-tanks at different levels. If the two tanks are connected by a pipe, the discharge of water from one to the other takes place because of the difference of level; water flows from that tank that has the higher level. In the case of electricity we use similar language, but use the word *potential* instead of level. If when two bodies are connected by a wire or brought into contact, positive electricity passes from one to the other, we say that there was a difference of electrical potential between them, and that the body from which the positive electricity passed had the higher potential. The transfer of positive electricity always takes place from a higher potential to a lower, and the transfer of negative electricity from a lower to a higher. When no water flows through two tanks on connection being made between them, we know they must be at the same level; and similarly if no discharge takes place between two bodies when they are electrically connected they must be at the same potential. Conversely, if they are at the same potential no discharge of electricity will be brought about by connecting them. If we can find a level of reference, we may speak of each tank as having a certain level, as for instance, so many feet above high water mark. Similarly, we may speak of a body as having a certain potential if we assume the potential of the earth to be zero. When water falls to a lower level it will do work, and when it has fallen from a higher to a lower level the difference of level cannot be restored without the expenditure of work. For every pound of water that is lifted through a difference of level equal to a foot, one foot-pound of work is done, no matter what is the shape of the path by which the transfer to the higher level is effected. If Q be a quantity of water and D a difference of level through which it is raised, then the work done is Q D. Similarly, electricity cannot be transferred from one body to another at a higher potential without requiring work to be done. If Q be the quantity of electricity and D the difference of potential, the work required to transfer Q up to the higher potential is Q D. If Q be 1, or unity, then the work required is measured by D. Hence we have the following definition: *Difference of potentials is a difference of electrical condition in virtue of which work is done by positive electricity, in moving from the point at a higher potential to that at a lower potential, and it is measured by the amount of work done by the unit quantity of positive electricity when thus transferred from one point to the other.*

Strictly speaking, potentials are relative, and it is always a *difference* of potential with which we have to deal. There are, however, two ways in which

we can speak of the potential at any point—a theoretical and a practical way. The theoretical method consists in calling the potential at a point the difference between the potential at that point and at a point a very long way from the electricity that produces the electrical force. Hence *the potential at any point is the work that must be spent upon a unit of positive electricity in bringing it up to that point from an infinite distance.*

If there be a quantity of electricity, q, at a point A, the potential due to q at a distance r from A will be $\frac{q}{r}$. *

The practical zero of potential is that of the earth; hence for practical purposes the potential of a body is considered to be the excess or defect of its potential above or below that of the earth in its neighbourhood.

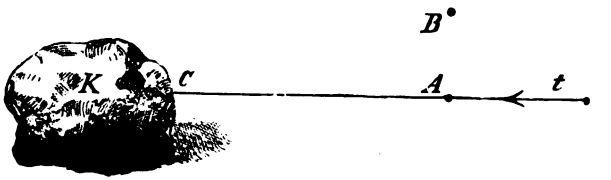


Fig. 28.—The Theory of Potential.

Illustrations.—Let K be an electrified body, and let t be a very small electrified particle (Fig. 28). If K and t have similar electricities they will repel

* Suppose at a point C there is a quantity q of electricity, and let A and B be two points on the same line, at distances r and $r+d$ from C, so that the distance A B is d. Let V_1 and V_2 be the potentials at A and B respectively due to q at C. Then the difference $V_1 - V_2$ is the work done in bringing a unit of electricity from A to B.

C r A d B

q V_1 V_2

The force at A between two quantities, q and 1, is $\frac{q}{r^2}$

The force at B is $\frac{q}{(r+d)^2}$

Hence the work (force by distance) required to carry 1 from A to B lies between $\frac{q\,d}{r^2}$ and $\frac{q\,d}{(r+d)^2}$.

As these are very near together, we may therefore take their geometrical mean as the quantity between them which we require.

$$\text{The mean} = \frac{q\,d}{r(r+d)} = \frac{q}{r} - \frac{q}{r+d}$$

$$\text{Hence } V_1 - V_2 = \frac{q}{r} - \frac{q}{r+d}$$

If $V_1 = \frac{q}{r}$ then V_2 to be of the same form must be equal to $\frac{q}{r+d}$, and this satisfies the equation. Therefore the potential at a point distant r from q is $\frac{q}{r}$.

each other, and the particle *t*, if free from the influence of other forces, will move from K into space. The motion of *t* is caused by the force of repulsion between the charges on the two bodies. Work would be required to restore *t* to its first position, and therefore work must be done in the repulsion of *t*. The amount of work done depends upon the force exerted and the distance which *t* has gone through; and it is measured by the product of the force and the distance. The amount of work done will not be affected by the path pursued by the particle *t* in passing from one position to another. Whether the particle in order to reach C takes the direction A C or the direction *t* B C, the amount of work done will be the same. It is not the direction, but the distance measured in the direction of the force, that determines the amount of work done. What holds good for *t* holds good for every other body surrounding K. Whatever point may be taken, a certain amount of work must be done to bring *t* to that point. The work done against the electrical repulsion between K and *t* in order to bring *t* from an infinite distance to a certain point, is the potential at that point due to the influence of K. Each point at a certain distance from the electrified body being at a fixed potential, the body must be surrounded by concentric areas or surfaces of equal potentials. These areas are called equipotential surfaces, and are such that all points on any one of them have the same potential. On different areas the potential is different, becoming smaller the farther away the respective area is from the electrified body. For example: if the body possesses a symmetrical shape, as that of a sphere, and is in a perfect homogeneous medium, the equipotential surfaces will be similar in form; that is to say, they will be spherical. Particles will be repelled in such a manner that they will move from equipotential surfaces of higher potential to those of lower potential; and each particle will choose the shortest way from one equipotential surface to the other. The curves which the repelled particles describe are termed lines of force. They are, as a rule, curves, the form of which depends on that of the equipotential surfaces, while the forms of these surfaces are determined by the shape of the body itself. Analogous lines of force we had in the chapter on magnetism (Figs. 3 and 8). The space these curves occupy is called a field, and we distinguish between magnetic and electric fields.

Electrometers.—We have now to consider how we can test the difference of potential of two bodies without causing a discharge of the electricity upon them. Instruments for this purpose have been devised by Dellman, Kohlrausch, and Thomson. Fig. 29 represents Kohlrausch's Torsion Electrometer. The arm *a a* is made of silver and fixed by means of the pieces of shellac *b b*. The beam of the balance, also of silver, hangs by the glass thread *i* in such a manner, that it is able to lean on both sides of the arm *a a*, in consequence of the bendings of the latter. The instrument is used for taking measurements in a way similar to that in which the "Torsion balance" is used. The most sensitive, and that most adapted for exact measurement of very small quantities of electricity, is, however, the quadrant electrometer of Sir William Thomson, which is now almost universally adopted in practical work.

The Quadrant Electrometer.—The characteristic features of this instrument are the following: A light body connected with the inner coat of a Leyden jar, by which it is charged, hangs near two bodies whose electrical state is to be tested. The difference of electrical condition is measured by the resultant attraction of the light body. In Sir William Thomson's instrument the light body is a very thin aluminium needle C, shaped like a figure **8**, shown by a dotted line in Fig. 30, and within the quadrants *a b* in Fig. 31. This flat needle is hung by a wire from an insulated stem inside a Leyden jar with hemispherical base (Fig. 31). This Leyden jar contains a cupful of strong sulphuric acid, which forms its inner coating. A wire stretched by a weight W dips into the acid, and connects the needle with this inner coating. The needle carries a small mirror, which serves, as in the reflecting galvanometer, to indicate the deflection by reflecting a beam of light on to a scale. The needle C hangs inside four quadrants A+, B−, C+, D− (Fig. 30), insulated by glass stems. The quadrant A+ is in electrical connection with C+, and B− is in connection with D−, as shown by the wires in the figure.

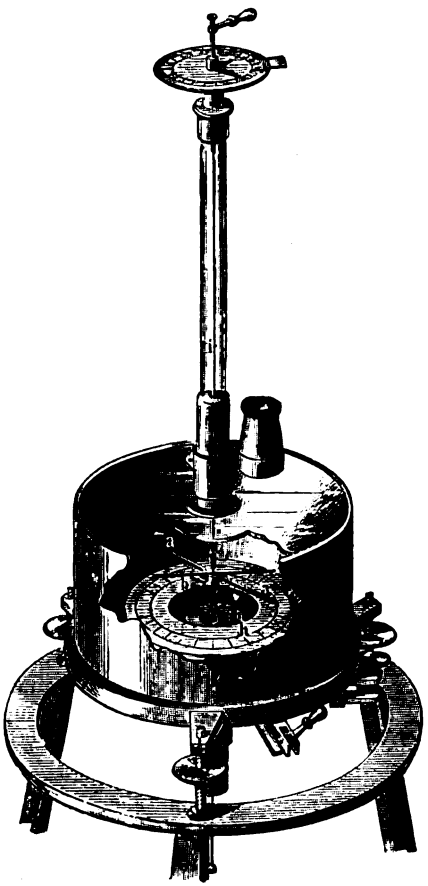


Fig. 29.—Kohlrausch's Torsion Electrometer.

Let us suppose the needle C charged to a high negative potential; then if the quadrants are symmetrically placed it will deflect neither to the right nor to the left, so long as A+ and B− are of the same potential. If B be negative relatively to A, the end of C under A and B will be repelled from B to A, and at the same time the other end of C will be repelled from D to C. The motion will be indicated by the motion of the spot of light reflected by the mirror, the deflection being sensibly proportional to the difference of potential between A and B. The number of divisions which the spot of light traverses on the scale will therefore measure the difference of potential between A and B. This instrument is, therefore, an electrometer, and not a mere electroscope.

Two terminals *l m* (Fig. 31) serve to charge A and B. They can be lifted up out of contact with A and B after charging them. The third terminal *p* is attached to a little electrical machine inside the jar called a *replenisher*, by which the charge of the jar can be increased at will. There is also a gauge by which the constancy of the charge can be measured. Some of these instruments are made so sensitive as to give a deflection of one hundred divisions for the difference of potential between zinc and copper in contact.

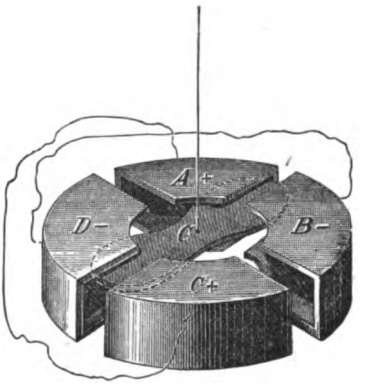


Fig. 30.—The Quadrants in Thomson's Electrometer.

Seat and Distribution of Electricity. — We have seen that every electrified particle free to move will travel from a high potential to a lower. If we charge a conducting substance with a certain quantity of electricity, each part of this electricity repels the rest, and, in consequence, moves from positions of high potential to those of lower potential. The electricity tries, so to speak, to disperse itself as far as possible. In fact, it will do so until an obstacle comes in its way. The electricity in the conductor itself moves very rapidly in all directions, and only encounters an obstacle at the surface of the conductor. If it be surrounded by dry air, which is a bad conductor of electricity, the dispersion stops at the surface. The surface, then, must have one potential only; if not, the electricity would move from it to a lower potential, or to it from a higher one. This may be expressed thus: Whenever the electricities on a conductor are

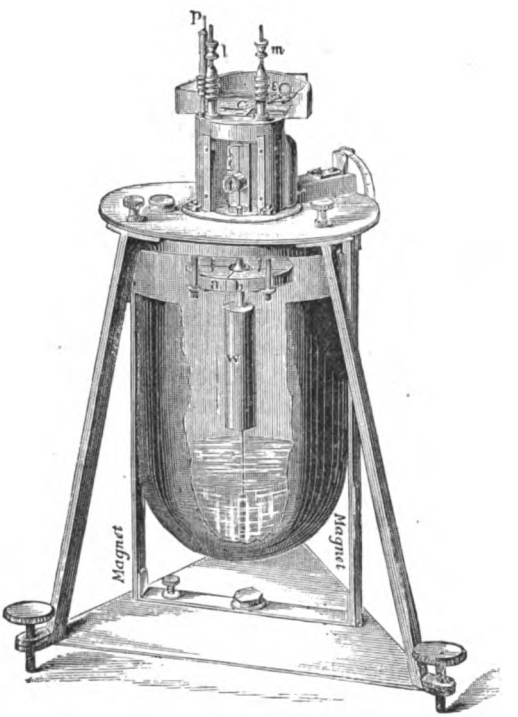


Fig. 31.—Thomson's Quadrant Electrometer.

in equilibrium, each part of the conductor has the same potential as the surface, and electricity is distributed only over the surface of the conductor. The surface of a conductor in electrical equilibrium is, therefore, an equipotential surface. To prove this experimentally an apparatus with a movable surface, as shown in Fig. 32, is used. The brass ball A rests on a glass rod, and can be accurately covered by the hemispheres B and C; both hemispheres have insulated handles. Cover A by means of B and C, and charge the apparatus; after the removal of B and C, A shows no sign of electricity, whilst B and C remain electrified. The experiment may be varied by first charging A, and then placing B and C over it. The electricity that was at first on the surface of A passes to the surface of B and C, and can be removed with them.

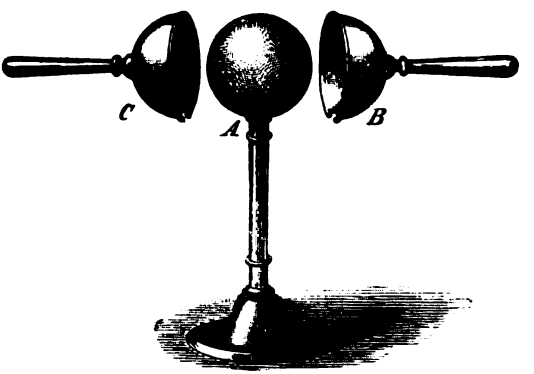


Fig. 32.—Conducting Sphere and Movable Hemispheres.

By means of the torsion balance it may also be proved that electricity resides only on the surface of bodies. Take two equal balls, one a brass ball, the other a wooden one, covered with a conducting material. Let these balls be of the same size as those in the torsion balance. The ball D (Fig. 26) is charged and inserted so as to touch B; D and B will have similar electricity, and the two balls will repel each other. If we touch D with the brass ball, it loses part of its electricity, and the angle diminishes accordingly; if, instead of the brass ball, we touch D with the covered wooden ball, the angle will be exactly the same.

The distribution of electricity on conductors of variable curvature is not uniform. At one portion of its surface the conductor has a larger quantity of electricity per unit of area than at another. In other words, the density of electricity at different places is different. Fig. 33 represents a conductor whose sections by planes in one direction are circles, and in a direction at right angles to the former (that is to say, through the axis) is a kind of pointed ellipse A B D C. The depth of the space marked off round this conductor is proportional at each point to the electrical density. Let us assume the distribution on the surface of the conductor to be at first uniform—a condition which we may represent by particles at equal distances from each other. Having so represented the distribution, and then supposed the particles to be endowed with a power of repelling one another, let us observe to what extent any one of the particles will influence its neighbour. The particle *a* is repelled by *b* in the direction *b f*, and by the particle *c* in the direction *c e* (the influence of the other particles on *a* need not be considered on account of their greater distance). If *a e* and *a f* represent the magnitudes

and directions of the forces *c* and *b* exercise on *a*, the resultant of these two forces may easily be found by completing the parallelogram *a*, *e*, r_1, *f*; hence *a* r_1 is the resultant. In the same manner we find the resultant of the forces acting on *c* (*a* and *d* acting on *c*) which is represented by the line *c* r_2. The resultant for the particle *d* is *d* r_3, and so on. We find the results become smaller the farther away from *a*. Particles on the cylindrical portion between A C and B D will have resultants equal o; therefore all the particles on this portion will be in equilibrium. The particles lying on the curve B *a* D are not in equilibrium, and the resultants that tend to move them become larger the closer the particles are to *a*. The reason for the increase of the respective resultants may easily be seen from the drawing. As the curve increases, the angle between the component forces becomes smaller, and the diagonal, or resultant, larger. The rate at which the density increases may be seen by comparing r_1, r_2, r_3 in Fig. 33.

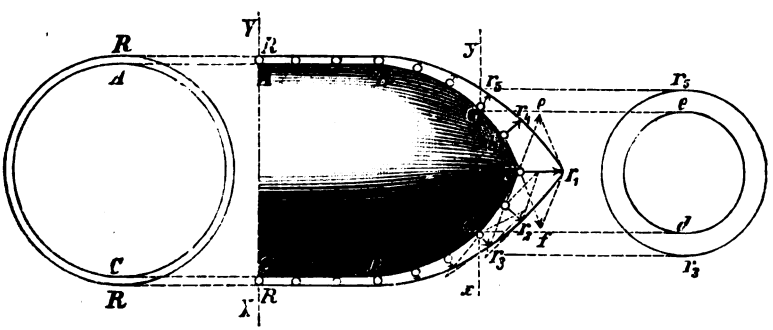


Fig. 33.—To Illustrate Surface Density.

We further find that at A B and C D the density is the same. We know of one solid only whose sections are similar or like each other in form, and that is a sphere. On it the density will be the same at all parts. On all other shapes electricity is not uniformly distributed. An ellipsoid, for instance, has its greatest density at the vertex. The distribution of electricity can be experimentally tested by means of the proof plane (a small piece of gold leaf or other conducting substance fastened to a glass rod). The proof plane removes electricity from the charged body without altering its condition to any considerable extent. The density found to exist on the proof plane will be the density at that particular place.

Point Discharge.—We have seen that the density depends on the curvature of the surface, and is greatest where the radius of curvature is smallest. We may imagine every curved surface to consist of superficies, which, according to the amount of curvature they have, may be parts of larger or smaller spheres. A level plain, therefore, may be said to be part of an enormously large sphere, a point part of a sphere infinitely small. The earth, in comparison to all other movable conductors, has an enormously large radius of curvature, and therefore the density of the electricity upon it must be proportionately small.

When a conductor terminates in a point, the density must be greatest at that point, no matter how small or how large is the charge of the body itself. Every electrified body loses its charge in time, the loss being due to leakage along the dirty or moist surface of insulators, or to moist air. As has been shown, all the electrified particles on the surface of a conductor struggle to get free of it, and are only kept in position by the medium which surrounds them. Whenever the density becomes great enough to overcome the resistance of the medium, the conductor cannot take up more electricity, and a further charge will flow into the air. In the dark we may observe that the passage of electricity from the conductor through the air is accompanied by light. The force which tends to separate the electrified particles from the conductor is called electric tension. Tension increases with density, and is therefore greatest where the radius of curvature is smallest (Fig. 33); therefore the tension will overcome the resistance of the air easiest at the points at which the surfaces have the least curvature. It follows that both tension and density must be greatest at a point, and if we could furnish a body with a mathematical point, there would be no possibility of charging such a body.

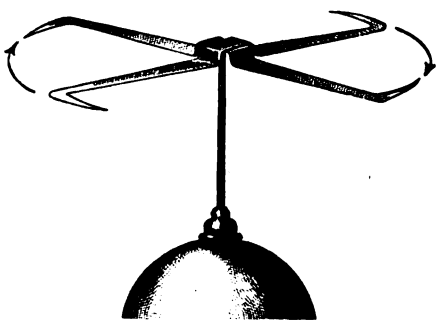


Fig. 34.—Electric Windmill.

The escape of electricity on account of its tension causes a current of air, called an electrical whirl; when the tension is very great this current becomes strong enough to blow out a candle flame. The flow of air from the point forward causes a pressure on the point backwards, for action and reaction are equal and contrary. To show this experimentally, an apparatus represented in Fig. 34 is used. It consists of metal bands or wires, having the form of an **S**, pointed towards the ends, and free to move on a vertical axis. The whole apparatus is placed on the conductor of an electric machine, as shown in the figure. As soon as the electricity on the conductor and apparatus (which, of course, consists of conducting material) has reached a certain tension, electricity rushes from the points, causing a motion of particles of air away from the points, and therefore the motion of the wheel in the opposite direction, indicated by the arrows. The efficiency of a point to effect discharge depends on its position; for instance, a point at *a* (Fig. 33) would act better than a point in A B.

A point in a conductor under induction may have the same effect as contact with the earth. For instance, K in Fig. 35 represents an insulated electrified ball. When an insulated brass cylinder is brought near *a b*, there will be induced in *a* the opposite electricity to that of K, and in *b* similar electricity to that of K. The first we will call electricity of the first kind, *b*; and the second, electricity of

the second kind. If now a point is screwed into the conductor at *b*, the second kind of electricity, on *b*, will flow from it into the air; in this it will be assisted by the similar electricity of K. When K is removed from *a b*, the latter will possess a charge (opposite to K) of the first kind; we see then that a point arranged as here causes electricity of the first kind to remain in the induced body after removal of the inducing body. If we alter the arrangement and put the point at *a*, but leave K in its former position, that is, opposite to *a*, we observe the following changes when K has + electricity. At *a* we have again − electricity, and at *b* + electricity; the point at *a* has − electricity also and causes the escape of − electricity. After the removal of K, *a b* remains

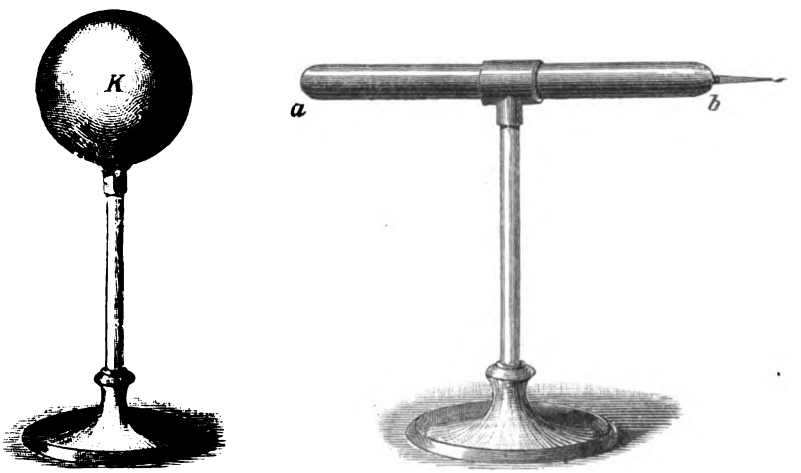


Fig. 35.—Point on Conductor under Induction.

charged with + electricity. But we find that the positive electricity in K has been diminished by the exact amount of the positive electricity in the cylinder. We know that bodies inducing electricity do not thereby diminish their own; how, then, are we to explain the action of the point? In consequence of the great density of the negative electricity at *a*, electricity escapes here, but also causes a different distribution of the positive electricity in K. The density on the ball K opposite the point becomes also so great as to cause electricity to escape towards the point. The escape of the − electricity from the point *a* is accompanied by a so-called electrical wind, by which the negatively electrified particles of air are thrown against the ball K; here, of course, they will lose their − electricity, and neutralise part of the positive electricity on the ball K. If we did not know what really happens, we should think the point at *a* drew the electricity from K over to *a b*. Again, when a positively electrified body has a point, and an unelectrified body is brought near this point, the unelectrified body will become charged with positive induced electricity. The great density of the positive electricity at the point in the charged body causes the

– electricity of the non-electrified body to flow over to the point, and at the same time some of the – electricity in the non-electrified body is neutralised by the positively electrified particles of air discharged from the point. The tendency of points to produce discharge must be taken into account in the construction of apparatus, and sharp edges, etc., must be avoided.

Glowing or Burning Bodies.—Flames on conductors produce the same phenomena as observed by means of points on conductors, etc. The formation of points in burning bodies is far more perfect than the artificial formation, and, as a result, the best way to make non-conducting bodies unelectrified is to draw them several times through a gas flame.

ELECTRICAL MACHINES.

To produce greater quantities of electricity we replace the glass or sealing-wax rods by the electrical machine. We will describe in succession the Disc or Plate Machine, Steam Electrical Machine, Electrophorus, and the best Induction Machines.

The *Plate Machine* in course of time has gone through many alterations; its essential parts, however, remain the same. Fig. 36 represents the form the Vienna electrician, Winter, has given it. The principal parts are the glass or ebonite disc S, the rubber R, and the two conductors C C. G_1 G_2 G_3 G_4 are glass rods used as supports. On G_1 rests one end of the wooden axis of the glass plate; G_2 supports the other end. G_3 supports a U-shaped piece of wood, which is so arranged that between each limb and the glass plate a rubber R may be inserted. These rubbers consist of flat pieces of wood covered first with some woollen cloth, and over this leather. The leather itself has a coating of tin, zinc, or mercury amalgam, and is pressed against the disc by a spring, which lies between the limb of the wooden U-shaped frame and the rubber. Both rubbers are connected with the negative conductor. The positive or prime conductor, a hollow brass ball, rests on the glass bar G_4. Wooden rings *r* run from the brass ball parallel to the glass plate on each side of it; the portion of the ring facing the glass plate is covered with tinfoil, which is in connection with the conductor, and carries metal points so arranged as to stand at right angles to the plate, and as near to it as possible without touching it. Winter, as a rule, further adds a wooden ring W, which has a spiral of metal in it. Experiments have shown him that this ring acts exactly as a sphere of the same radius would do. It is a kind of collector or condenser, and on adding the ring, therefore, the length of spark obtained from the machine is considerably increased. On the side of the conductor C, opposite to the two rings, is a small brass ball, where the density is always greater than at any other place on the conductor. A spark will pass most readily from this little ball over to a discharger E, brought near the conductor. By means of the handle K the machine is worked in the direction of the arrow. The glass plate is rubbed against the amalgamated rubber, and becomes positively charged.

Glass being a bad conductor, the electricity does not spread all over the plate, but remains where it is produced. If we continue to work the machine, the parts of the plate having positive electricity will come under the metal points of the wooden rings *r*. The positive electricity of the plate will now decompose the neutral electricity in the positive conductor c. By forcing the positive electricity to the farthest end of the conductor, and attracting the negative electricity, it will cause a discharge at the metal points of *r* on to the plate s. This induced – electricity will neutralise the + electricity of the glass plate, and the glass plate will leave the metal rings unelectrified. But new positive electricity can now be produced in the same manner, and the process be repeated; if we continue to rotate the plate s, the positive electricity in the conductor will accumulate; we also know that we produce positive and negative electricity in equal quantities; what, then, has become of the latter? Negative electricity is produced on the rubbers, which, as we have mentioned, are connected with the negative conductor c. Hence the negative electricity produced passes directly to the – conductor, and accumulates there. If now we continue to rotate the disc, the collected – electricity will soon have a sufficient density to unite with the positive electricity. They will then neutralise each other, and the efficiency of the machine will be at an end. To prevent this, the negative electricity is passed to the earth by attaching a chain to the negative conductor. By continued rotation the charge of the positive conductor will now increase. We cannot, however, continue this process very long, as the density on the positive conductor will ultimately

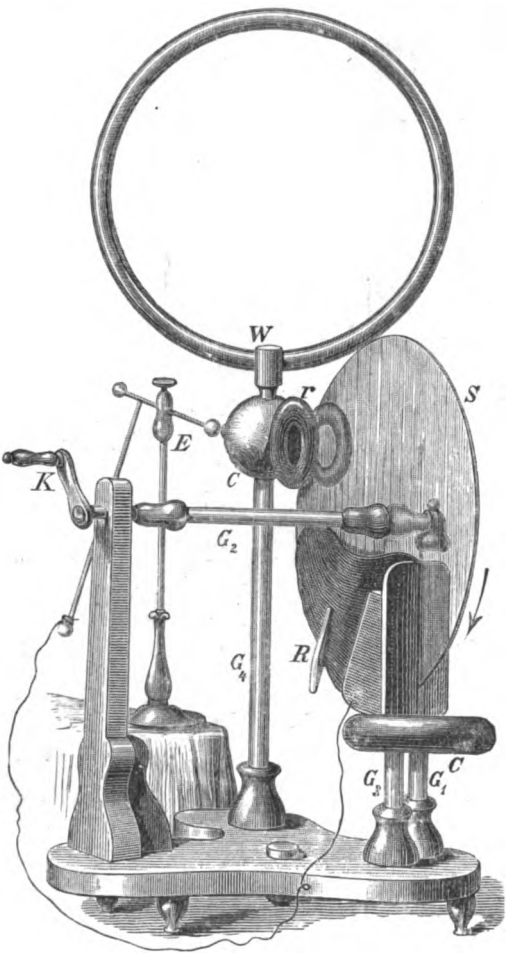


Fig. 36.– Winter's Electric Machine.

become so great as to allow the electricity to flow back through the metal points when the unelectrified portion of the glass plate is near *r*. When the conductor has this tension, the positive electricity in the glass plate is not any longer able to cause the induced negative electricity to flow through the metal points. When, however, the positive electricity is also conducted away, the machine will be a continued source of electricity as long as the plate rotates. If only sparks are required, the chain suspended from the negative conductor is brought into contact with the discharger, as shown in the figure. If we require − instead of + electricity, the chain is removed from the negative conductor, and placed on the + conductor. We can then collect the negative electricity from the lower conductor.

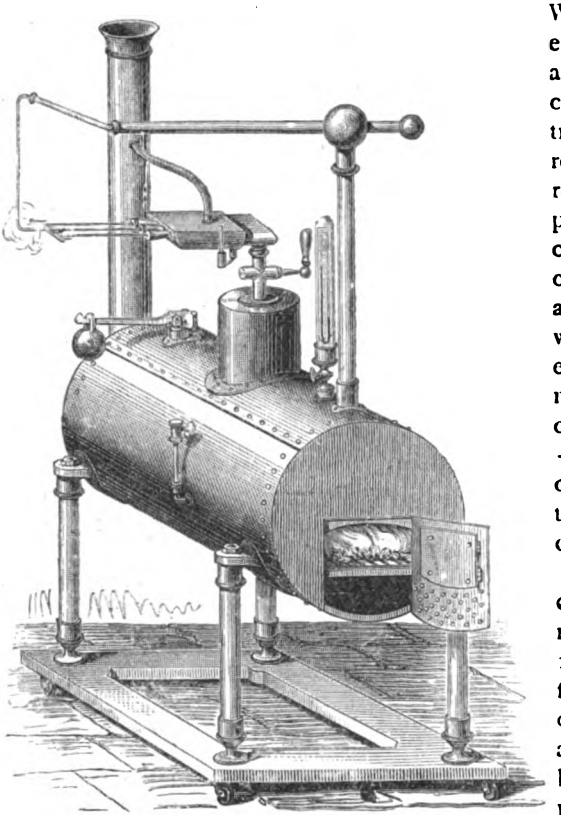


Fig. 37.—Steam Electric Machine.

Hydro-Electric Machine.—An engine-driver named Seghill observed in 1840 that the steam escaping from a safety-valve may become electrified. Armstrong and Pattinson insulated the boiler, and placed metal points opposite the escaping steam. The metal points were in connection with a conductor. These experiments showed that the steam became positively electrified, and the boiler negatively.

Armstrong constructed the machine represented in Fig. 37. The boiler rests on four strong glass pillars, and is furnished with a safety-valve, a manometer, and a steam dome, from which the steam passes to the escape pipes. In its passage the steam has to go through a kind of iron box, in which it is partly condensed, because it is of importance that the steam should carry as much moisture as possible. The escape pipes are made of different forms by different makers; the chief object, however, in all, whatever their shape, is to increase the friction of the water globules. To increase friction, Faraday placed

a cone with the point against the issuing steam. Armstrong placed a disc in front of the steam. The issuing steam strikes against a series of metal points in connection with the conductor. The + electricity then collects on the conductor, whilst the - electricity distributes over the boiler.

The Electrophorus.—As early as the year 1762 Wilke had made careful experiments with electrified glass plates, but Volta was the first to devise the electrophorus (1775).

A simple electrophorus is represented in Fig. 38 : A is a cake of resin, B and C metal discs connected by means of silk threads, *i* the insulating handle. Fig. 39 is intended to show what happens when the electrophorus is charged ; here M is the metal form on which the cake rests, H the cake of resin, D the metal disc, which is sometimes called the carrier, and G the insulating glass handle.

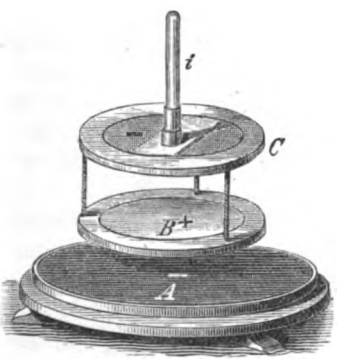


Fig. 38.—Electrophorus.

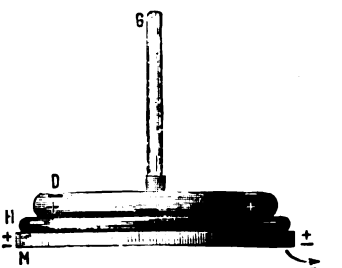


Fig. 39.—The Theory of the Electrophorus.

By rubbing the cake it is negatively electrified. If now the disc is placed upon the electrified cake, the negative electricity of the cake influences the neutral electricity on the disc, the + electricity is attracted by the – electricity of the cake to the lower surface of the disc, and the – electricity is repelled to the upper surface of the disc. If the upper disc is now touched with the finger, the – electricity is conducted to the earth, and the + electricity is held fast by the negative electricity of the cake. If the disc be now lifted, it retains its charge of positive electricity, which may be used as required. The discharged disc can be again charged, by placing it, as before, on the resin cake A, then touching it with the finger. It may be again lifted and discharged many times without removing the charge of the cake. The negatively electrified resin cake not only influences the electricity on the disc, but also that on the lower side of the cake itself, and the electricity of the tray in which the cake is cast.

Riess and Bezold devoted much time to the observation of these phenomena. The result of their researches is given in two theories, which do not exactly agree. Bezold attributes the negative electrical condition of the tray to the direct action of the negative electricity in the upper surface of the resin-cake. Riess assumes the negative electricity in the tray to be induced, being first

generated in the resin cake, and then by induction imparted to the tray. Whichever explanation we adopt, it will be easy to account for what really takes place.

If at any place on the surface of the resin-cake we place a strip of tinfoil about one centimetre wide, connected with the metal tray in which the cake rests, we shall find that when the disc or carrier is placed on the resin and is then taken off, without having been touched with the finger, it is positively

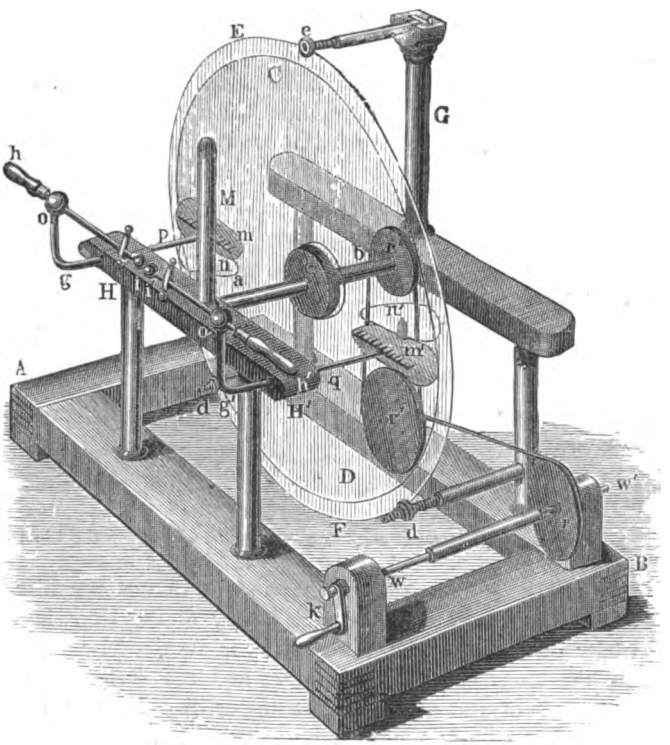


Fig. 40.—Holtz's Machine.

electrified. The tinfoil connects the surface of the resin with the earth, but only conducts negative electricity from the spot at which it touches the resin. Other portions of the surface are hardly influenced at all, for resin is a very bad conductor. By means of the tinfoil the negative electricity of the tray is also conducted to the earth, and the positive electricity is held fast or bound by that of the resin cake. When the carrier is placed on the resin, + and − electricity are induced. This + induced electricity is bound by the − electricity of the resin cake. The negatively induced electricity flows to the earth by means of the tinfoil. If now the disc be removed, the positively induced electricity spreads all over the surface, and thus the disc appears positively electrified. The piece

of tinfoil saves the repeated discharging of the disc. If an electrophorus, after having been electrified, be set aside with the disc in its place, it will retain its electricity for months. It is this property of the instrument to which its name is due; that is, electrophorus, or bearer of electricity.

Induction Machines, or Continuous Electrophori.—In producing electricity by friction, glass rods, etc., were replaced by machines which would perform the operation more continuously; and in a similar manner the principle of the electrophorus has been extended in the construction of what are called continuous electrophori, or electrostatic induction machines. Instruments applying the same principle have been constructed by Varley, Thomson, Carré. Holtz, Voss, Wimshurst, and others. The form shown in Fig. 40 is that devised by Holtz, of Berlin. The wooden frame A B supports the well-varnished glass plate E F by grooved pulleys *d d d* supported on glass pillars. This fixed plate E F has three openings; the one in the middle allows the axis of the rotating second plate C D to pass, the second opening is at *n*, and the third at *n'*. These latter form sector-shaped windows in the plate. Just above the opening *n* and under *n'* are glued on the farther side of the plate E F paper inductors *m m'*, from the edges of which tongues of card project and pass through the windows *n n'*, so as to touch the revolving plate C D. The plates, inductors, and tongues are carefully varnished with shellac varnish. The plate C D can be rapidly rotated. Opposite to *m* and *m'* series of fine metal points are so arranged that C D moves between them and the plate E F. The metal points are held by brass bars *p g o* and *q g' o'*, which terminate in the balls *o* and *o'*, through which metal rods run, having the insulated handles *h h'*, and the small spherical terminals *i i'*, termed the poles of the machine.

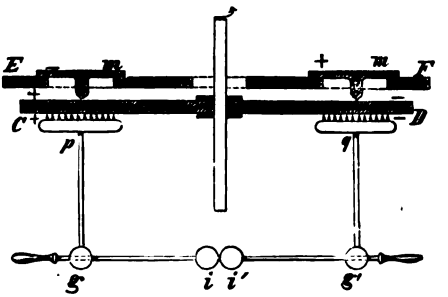


Fig. 41.—Diagram of Induction Machine.

What takes place when the machine is in action is of a very complicated nature, and can hardly be said to be perfectly understood. Fig. 41 is a diagram to aid us in our explanation, the parts having the same letters as before. The two balls *i* and *i'* touch each other. To the inductor *m* on the stationary glass plate E F is communicated from some external source a charge of − electricity, which is usually effected by approaching a loose piece of ebonite excited by friction. This affects the movable plate C D and the metal points *p*. The plate C D then becomes positively electrified on that side facing the inductor *m*, and the side facing the metal points becomes negatively electrified; but the negative electricity on − *m* influences the whole system *p*, *g*, *i*, *i'*, *g'*, *q*. While the + induced electricity is drawn towards the points *p*, the − induced electricity is driven through *g g'* into the points at *q*. Positive induced electricity will flow over at the points *p*, and spread over C D; here it will meet the negative

electricity induced by the inductor *m*, and the two electricities will partly neutralise each other. The surplus of + electricity leaves the plate C D positively electrified. The result then is, that C D becomes positively electrified on both sides. If now the glass plate is moved in the direction of the arrow round its horizontal axis, the positively charged sides of the plate C D come between *q* and the inductor + *m*. To the metal points or comb *q*, as has been mentioned, negatively induced electricity is forced. This flows over to the plate C D, meeting the positive electricity; the two electricities will neutralise each other, and the space on C D will have negative electricity. At the same time, the other side of the positively charged plate has come opposite to + *m*, and affects the unelectrified inductor + *m* in the following way: The plate C D brings positive electricity to the inductor, and induces + and −; the former, being similar to that on C D, is forced back into the conductor, the latter (negative) is drawn towards the point of the inductor. The − electricity flows over and neutralises the + electricity of the plate C D, besides charging the surface negatively. The plate comes to the inductor + *m* with positive electricity and leaves with negative. The result, then, of the action of inductor + *m* and comb *q* on plate C D is that the glass plate C D is charged on both sides negatively; at the same time, the inductor *m'* becomes charged positively.

It is evident that every spot on the glass plate undergoes the same process if the machine be worked. The portions of the plate C D, which at the beginning of the operation came between − *m* and *p*, receive here positive electricity, which is retained until they reach + *m* and *q*. Exactly the same thing happens with every portion of the plate which moves in the direction − *m p* to + *m q*. Hence the upper portion of the glass plate will be continually charged with + electricity. As the plate moves on the parts travel from − *m p* to + *m q*, where they become negatively charged, consequently the lower half of the plate must have a continual negative charge. What happens now, when the plate negative on both sides comes between *m* and *p*? The − electricity on the side facing E F goes over to the inductor *m*, and thus increases the − charge of *m*. The − electricity facing comb *p* is neutralised by the + electricity flowing from *p*, and the plate itself is positively electrified. The strengthened charge in *m* affects C D and comb *m*. The same phenomenon is now repeated as at the beginning, except that the effect will be greatly increased. The plate C D between *m* and *p* again becomes positively charged, but much stronger than at the first revolution, and the positively charged portions again reach + *m* and *q*. Each turn then augments the charge in a continually increasing ratio. If the two balls *i i'* be now moved from each other, a splendid brush may be observed. If a Leyden jar is placed between *i i'*, sparks will pass at intervals with loud reports.

When the two poles *i i'* of the induction machine are in contact, the positively and negatively induced electricities are neutralised in the conductor *g g'*, as has been mentioned. It is said the conductor *g g'* has an electrical current flowing through it. We shall show in a subsequent chapter how the electric

current is more usually produced by a galvanic cell or battery, and we shall then consider whether there is any difference observable between these two electrical currents.

Small Leyden jars or condensers, the action of which will be presently explained, are usually employed in connection with these machines to strengthen the spark, and are often mounted permanently as part of the apparatus, large tubes fitted up as jars taking the place of glass pillars employed for insulation.

Quite recently A. Toepler has constructed induction machines, which greatly surpass Holtz's machines in efficiency. He himself describes them in the following words: "Little glass discs are fixed at intervals on a horizontal axis. Alternate intervals are taken up by stationary glass discs, with inductors; these, however, are so arranged that there are only half as many inductor plates as there are rotating plates. In the remaining intervals combs having a series of points are introduced. If we imagine the inductors to be charged on the right side positively, on the left negatively, each inductor influences two discs; in the same manner each comb influences two plates. If now the different series of points be connected by means of a wire, a current of considerable strength will be induced. I caused an instrument to be constructed which had twenty circular discs, each having a radius of 13 centimetres. The whole apparatus took up only a space of 0·05 cubic metre." Toepler connected three such machines together, and obtained a current which maintained a platinum wire 0·2 millimetre thick continually at a red heat. This apparatus was also capable of decomposing water. Toepler says: "Twenty years ago about one hundred electrical machines would have been required to produce these galvanic effects."

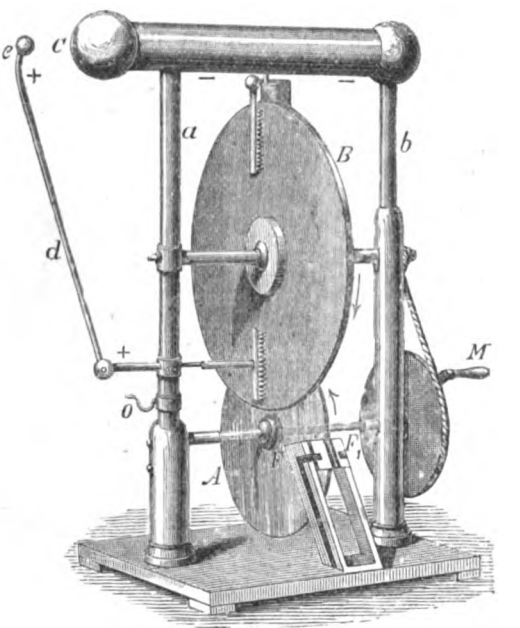


Fig. 42.—Carré's Machine.

In France, the machine shown in Fig. 42, constructed by Carré, is mostly used. It combines the frictional action of the older machines, with the inductive principle of the Holtz pattern. In this machine both plates, the inducing and the induced, are set in rotation. The former A is of glass, and is kept charged with electricity by means of the two rubbers F F_1, and

rotates much more slowly than the latter (B) of ebonite, which rotates in the opposite direction, the two overlapping each other and being nearly, but not quite, in contact. The handle M and the cord passing round the pulleys are the means by which the motive power is transmitted to the plates. The axes of both plates are fixed into the insulating pillars *a* and *b*, upon which the prime conductor C rests. One of the collecting combs is connected with the conductor C; and the other is provided with a movable arm *e d*, which can be brought into contact with the conductor, or removed from it. The inductive action of this apparatus is very similar to that of Holtz's machine, with the exception that there are no armatures whose charges are increased by

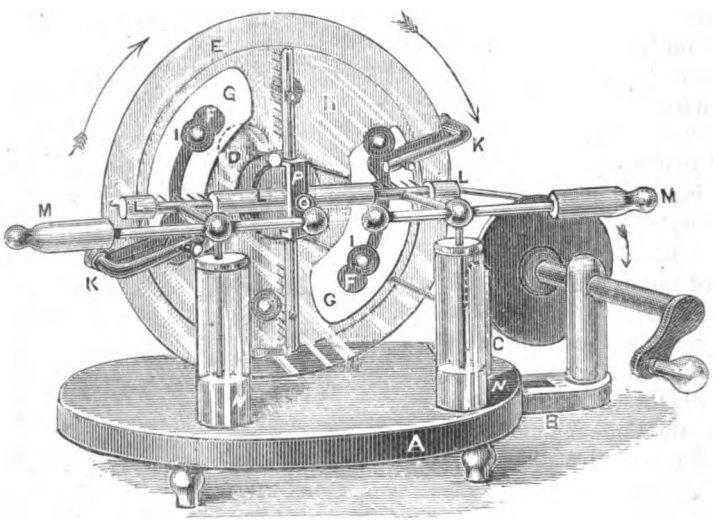


Fig. 43.—Voss Induction Machine.

induction, their place being taken by the disc A, which is kept charged by the friction of the rubbers F F_1.

The Voss Induction Machine.—In this machine there is a fixed plate of thin glass E, say 12½ in. in diameter, with a central opening of 3 in. which has fixed upon its farther side two pairs of tinfoil discs, connected by a strip of foil. These discs F F are covered by paper shields G G, which serve as collectors from the surface of glass covered by them. The moving plate H is of 10¼ in. diameter, and at six equi-distant points of a circle of 7½ in. diameter, are fixed inch discs of tinfoil, upon the middle of each of which there is cemented a metal button, rising ⅛ in. from the surface. These discs *i i* correspond to those of the fixed plate. The collecting system consists of an ebonite rod L, which is held horizontal by means of the axis, and two steel pins on the face of the nut. At each end is a brass T-piece, carrying

a collecting comb, and on the other arm a ball which carries the discharging rod M, and is supported by a small Leyden jar N.

A second pair of combs, shown vertical, are attached to a brass frame P, also placed on the axis, and secured there by a knob of ebonite screwed upon the end. These combs have fine wire brushes in their middles, which touch the buttons and short circuit the discs so as to discharge them just as they leave the paper shields, over the ends of which the zero comb should be placed. K K are bent arms of metal, attached by clamps to the fixed plate, and connected by strips of foil to the nearest foil disc. These arms carry fine metal brushes, which are adjusted to touch the buttons on the moving plate at the instant they face the foils on the fixed plate, so as to close a circuit at that moment.

This machine is exceedingly powerful in favourable weather, but has an important defect, in a tendency to *self-reversal*, which is apt to occur at a stoppage. This defect is not found in the next machine described, but can be produced in a Voss machine when desired by holding a metal point to the + brush K. The two derived inductive circuits are beautifully manifested when this machine is worked in the dark. A luminous stream is seen pouring towards the collecting comb L, on whichever side of the machine the comb is +.

Wimshurst's Influence Machine.—This machine, invented by Mr. James Wimshurst, one of the consulting engineers to the Board of Trade, is the latest in date (about 1883), and the most powerful of the induction machines yet constructed. It consists of two circular discs of thin glass, which are attached to loose bosses revolving on a fixed horizontal spindle, in such a way as to be rotated in opposite directions at a distance apart of not more than about one-eighth of an inch. Each disc is driven by a cord or belt from a large pulley, of which there are two attached to a spindle below the machine, and which is rotated by a winch handle, the difference in the direction of rotation being obtained by the crossing of one of the belts. Both discs are well varnished, and attached by cement to the outer surface of each are twelve or more radial sector-shaped plates of thin brass or tinfoil, disposed around the discs at equal angular distances apart. These sectors take the place of the "inductors" of Holtz's instrument, and appear also to act as carriers, though the exact nature of the action is somewhat mysterious. It appears, however, probable that those acting for the time as carriers on the one disc, act at the same time as inductors to the other. The two sectors situated on the same diameter of each disc are twice in each revolution momentarily placed in metallic connection with one another by means of a pair of fine wire brushes attached to the ends of a curved rod, supported at the middle of its length by one of the projecting ends of the fixed spindle upon which the discs rotate; the metal sector-shaped plates just grazing the tips of the brushes as they pass them. The position of the two pairs of brushes with respect to the fixed collecting combs, and to one another, is variable, and there is, as in the case of the collecting commutator-brushes of dynamo-electric apparatus, a position of maximum efficiency. This position appears to be generally when the brushes touch the disc on diameters

situated about 45° from the collecting combs, and the curved rods on the two sides are at right angles to one another, as shown in the engraving.

The fixed conductors consist of two forks furnished with collecting points

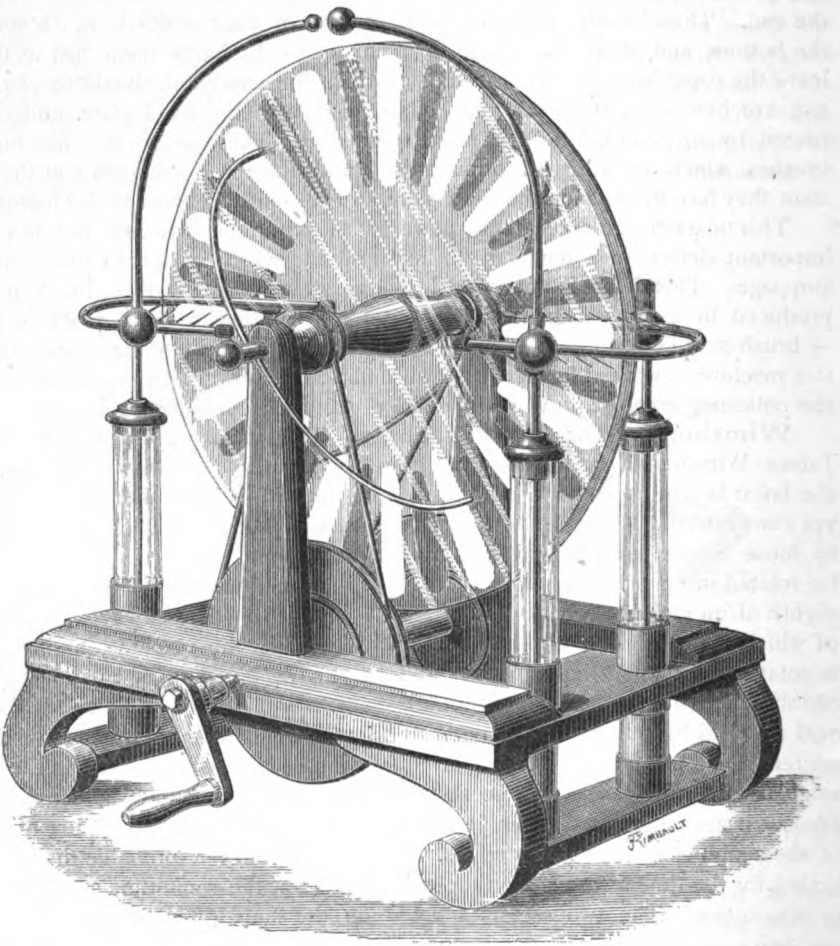


Fig. 44.—Wimshurst's Machine.

directed towards one another and towards the two discs, which rotate between them; the position of the two forks, which are supported on insulating supports of some kind, often (for reasons already indicated) consisting of small Leyden jars or condensers, being along the horizontal diameter of the disc. To these collecting combs are attached terminal knobs, whose distance apart can be varied by projecting ebonite handles, or otherwise. The presence of these col-

lecting combs appears to play no part in the action of the apparatus, except to convey the electric charge to what may be termed the external circuit; for the inductive action of the machine is quite as rapid and as powerful when both collectors are removed, and nothing is left but the two rotating discs, and their respective contact or neutralising brushes. The whole apparatus then bristles with electricity, and if viewed in the dark presents a most beautiful appearance, being literally bathed with luminous brush discharges.

With a machine composed of two glass plates only 14½ inches in diameter there is produced, under ordinary atmospheric conditions, a powerful spark discharge between the knobs when they are separated by a distance of 4½ inches, a pint-size Leyden jar being in connection with each knob; and these 4½-inch discharges take place in regular succession at every two and a half turns of the handle. It is usual to construct the machine as shown in the illustration, with small Leyden jars or condensers attached to conductors, by which the spark is materially increased. A machine has been constructed for the Science and Art Department, South Kensington, with plates 7 feet in diameter, which it is believed would give sparks 30 inches long; but no Leyden jars have been found to stand its charge, all being pierced by the enormous tension.

This machine is self-exciting, and it is believed that the initial action must be due to friction in the layer of air contained between the two plates. It is also, when properly constructed, nearly independent of atmospheric conditions, and not liable to reverse its polarity, as are the Voss machines. These advantages, added to its extreme simplicity of construction, have rapidly given the machine preference for all purposes where statical electricity of high tension is required. The property of self-excitation is found to depend somewhat on the number of sectors. With a higher number the machine excites itself very freely, but the sparks are more feeble; with fewer sectors it is less easy to excite, but the sparks are much more powerful when obtained.

It will have been gathered from the foregoing that (as might have been expected) when using induction machines the moisture of the air often causes experiments to fail, especially before large audiences. The atmosphere becomes saturated with moisture, and it is often impossible to get the machine in working order. Toepler tries to prevent this by placing the whole machine on a kind of stove. Dr. S. T. Stein covers the whole machine with a glass case, in which he places desiccating substances, and employs a small force-pump to force the moist air of the case over tubes containing desiccators and the dried air back again into the case. The Wimshurst machine and that of Carré (in the latter case owing to its direct action) are the least subject to these defects of any that we are acquainted with.

APPARATUS FOR THE ACCUMULATION OF ELECTRICITY.

General Explanation of Condensers.—Friction machines and inductive machines generate electricity in considerable quantities, and both possess

apparatus to collect the generated electricity, viz. the prime conductors. Accumulation, however, is possible up to a certain point only, and ceases when the potential of the conductor becomes so great that the metal points become ineffective. Induction gives us a means of collecting greater quantities of electricity. The various forms of apparatus which permit of such storage as we are here considering, are all called *condensers*, or *accumulators*. The Leyden jar and Franklin's square are examples. The principle is the same in all, and the essential elements are two conducting surfaces placed parallel to each other, separated from each other by an insulating medium, sometimes termed a *dielectric*. The following points, therefore, may be noted with all condensers: 1. If one plate B be removed, and the other A connected with a source of electricity, the latter will receive a charge depending on its capacity and the potential of the source. 2. If now the other plate B be restored, the charged plate acts inductively upon it, and if it be connected with the earth, the like electricity to that on A passes away, and the opposite electricities on A and B are "bound" by each other's attractions. 3. More electricity may then be given to A, and will act in a similar manner. Hence we *increase the capacity of a conductor when we place near it another conductor charged with the opposite kind of electricity*. To charge such an apparatus, one of the surfaces is brought in contact with the source of electricity, the other surface connected with the earth; the former is called the collector, the latter the condenser. Riess has given the accumulator a very convenient form, especially for the purpose of studying it. The apparatus is represented in Fig. 43; A is the collecting plate, B the condensing plate. The latter has a joint, *g*, which permits the plate B to be moved away from A; and the former a foot *r* which slides along the scale T; *k* is a screw which holds the conducting wire. The insulating medium between the two plates is the air. The plate B is at first pulled down, and plate A at *k* is connected with some source of electricity, such as the prime conductor of an electric machine, from which electricity flows upon A until the density in the conducting wire is equal to the density in the source of electricity itself. Plate B is then placed in its former position, that is, parallel to A. The electricity on A influences plate B and decomposes its neutral electricity. The induced electricity of opposite kind to that of the source is brought to the side facing A, and the induced similar electricity is forced to the side opposite or (when B is connected with the earth)

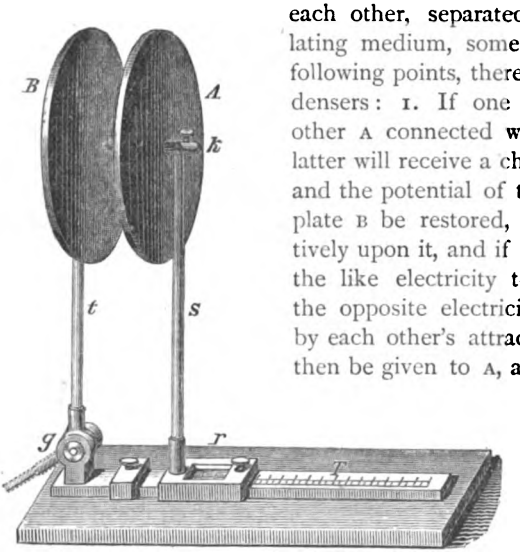


Fig. 45.—Riess's Condenser.

into the earth. The plate B possesses now a quantity of the first induced electricity, which causes the electricity in plate A to spread more over the side facing B. This of course diminishes the density on the other side of plate A, and also in the conducting wire. The density between the conducting wire and the source of electricity being different, it follows that more electricity will flow through the conducting wire to A. A stronger charge on A induces a stronger charge on B. But the electricity on B again influences A, as before, causing once more a difference in the density between source and conductor, and new electricity may again be conducted to A.

In this manner the collector and condenser accumulate more and more electricity. This process, however, cannot be continued for any length of time, because the density on the collector at each step is not reduced to that reached in the previous step, and therefore ultimately becomes the same as that of the source of electricity itself, when further accumulation of electricity is prevented. The total accumulation of such an arranged condenser is expressed by the coefficient of accumulation, showing how much more electricity the collecting plate is capable of accumulating when opposite to the condensing plate. The coefficient of accumulation then would be the quotient of the capacity of the condenser by the capacity of the single plate when charged alone. The value of the co-efficient of accumulation of different condensers depends on circumstances. Its value becomes less when the plates are further from each other; its value is increased when the connecting wire is considerably shortened. To make use of other insulators instead of air also increases the value of the coefficient of accumulation. The coefficient by which the capacity of an air condenser must be multiplied in order to give the capacity of the same condenser when another dielectric is substituted for air, is constant for each substance, and is called the specific inductive capacity of the dielectric.

The following table after Boltzmann shows by what coefficient the charge in the plates increases when, instead of air, the following insulators are used as dielectric:

Sulphur	...	...	3·84
Resin	...	...	2·55
Paraffin	...	...	2·32
Ebonite	...	...	3·15.

It is evident, therefore, that the dielectric itself is affected by the charge. We may explain its condition by the following assumptions:—It is assumed that the molecules of the insulator have + electricity at one end, and − at the other. All molecules in the insulator will point with their positively electrified ends towards the negatively electrified plate, and with their negative ends towards the positively electrified plate. This condition is called dielectric polarisation. It leads to the existence of strains or stresses in the dielectric, and is embodied in the following hypothesis: *The electric force acts across space in consequence of the transmission of stresses and strains in the medium with which space is filled.*

This accounts for the occasional disruption of the glass forming the condenser, and the fact that after discharge the glass does not recover itself all at once, and after a short time is able to give up a residual charge.

Volta's Condensing Electroscope.—The condenser used by Volta was attached to an electroscope, as shown in Fig. 46. This was the instrument he used to detect the electricity from such a feeble source as that supplied by two metals in contact. The lower plate was connected with the source, the upper plate being at the same time joined to "earth," or touched with the hand. By this means the two plates accumulated opposite charges, which remained "bound" by one another. When the upper plate was lifted off, the charge in the lower was free to distribute itself and spread to the gold leaves.

Fig. 46. — Volta's Condensing Electroscope.

Volta's condenser was not available for actual measurements, but the following is a form that may be used for this purpose:

Kohlrausch's Condenser.—Kohlrausch used a condenser admitting of very exact adjustment, of which the following is a description: Two brass plates *t t* (Fig. 47), of about fifteen centimetres in diameter, are fixed to horizontal rods, which are attached by means of shellac to the two wooden supports *b* and *c*. Those sides of the plates which face one another are covered with gold, and the ends of the rods are provided with binding screws to receive the conducting wires. The supports, together with the plates upon which they rest, stand upon the large sole plate *a*, upon which the whole apparatus rests. The sole plate can be placed horizontally by means of levelling screws. The support *b* can be moved towards *c*, by means of two forks attached to the under side. A silk thread passing over two pulleys, has one end attached to *b*, and its other end to a weight, thus tending to move *b* towards *c*. The spring *d* and the catch *e* serve to liberate *b*, or to arrest its motion.

The support *c* is not movable forward towards *b*, but is provided with adjusting screws to bring the condensing plate attached to it parallel to the condensing plate attached to *b*. The turning of *c*, and therefore the motion of the plate underneath it, is effected by means of the screw *k*, and the spring *i*. *c*'s inclination can be changed by means of the screw at *g*, and the spring at *h*. We can alter the distance between the condensing plates by simply turning the screw *n*.

The apparatus is used in the following way: The condensing plates are brought near one another, one of them being connected by means of the conducting wire with the source of electricity under examination, and the other with the earth. The plates are then removed from one another to a distance of about 0·1 metre, and the condensing plate is discharged. This distance

of 0·1 metre is sufficiently great to prevent the plates from influencing each other. The electricity on the collecting plate is then examined in the way already described.

Franklin's plate is shown in Fig. 48; the wooden frame *h* has a glass plate *g*, covered with tinfoil *s s*. To charge this plate, the coating of one side is

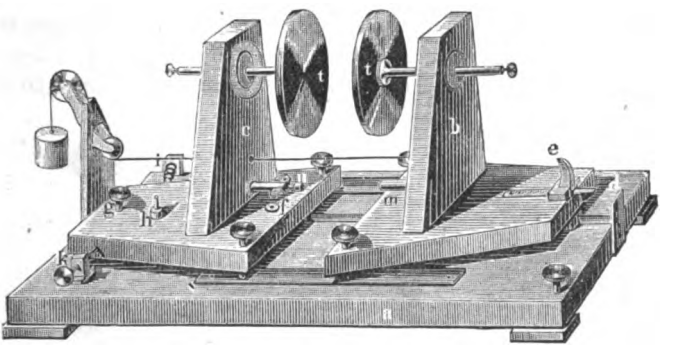


Fig. 47.—Kohlrausch's Condenser.

connected with the source of electricity, the other has a wire leading to earth; when *k l* is moved in the position shown by the dotted lines, *k* touches the tinfoil, and conducts the electricity to earth by means of the wire which is connected with *k*. In the behaviour during charge and discharge, there is no difference between this instrument and the condensers previously described.

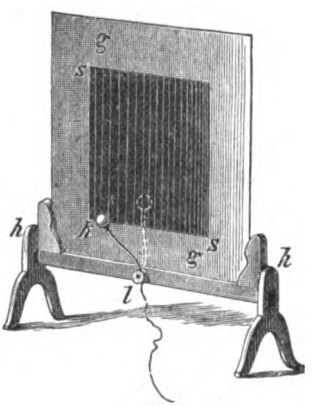


Fig. 48.—Franklin's Plate.

The Leyden Jar.—A very useful form of condenser is called, from the city in which it was invented, a Leyden jar. It is like a Franklin's plate bent into the form of a cylinder or jar. A Leyden jar is shown in Fig. 49. The glass cylinder has tinfoil inside and outside. The metal frame is placed inside the cylinder. Fig. 50 is an old medicine bottle, having iron filings gummed to the inside.

To charge a Leyden jar, the hand is placed on its outer coating, and the knob is allowed to touch the conductor of an electrical machine. The electricity reaches the inner coating by means of the metal rod, and induces electricity on the outer coating; the dissimilar electricity is bound whilst the similar electricity goes through the hand to the earth. The inner coating then represents the collecting plate, and the outer coating the condensing plate. The jar is said to be positively charged when positive electricity is led to the inner coating, that is, when the knob is connected with the positive conductor of an electrical machine.

Batteries of Jars.—To obtain very powerful charges, we might use very large jars or plates; this, however, would be inconvenient, and the method adopted is to connect several jars in a form called a battery. The charge of such a battery increases proportionally with the number of jars; for instance, eight jars will have a charge, compared to the charge of two jars = 4 times 2. Fig. 51 represents such an arrangement of jars. A table resting on glass supports has brass bands on its upper surface, so arranged that all the outer coatings of the different jars are touched by them. The knobs of the jars have metal rods terminating in balls. The knob of the centre jar B is bigger

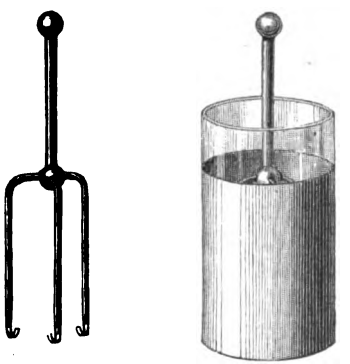


Fig. 49.—Leyden Jar.

Fig. 50.—Leyden Flask.

than the remaining ones, and to it the metal rods are fastened. On B is an arm terminating in a little ball; to charge the apparatus this ball is placed on the conductor A of an electrical machine, whilst the outer coatings have connection with the earth. The time to charge this apparatus will be $x \times$ the number of jars, if x stands for time in which one jar is charged. The whole apparatus, however, might be charged in the number of seconds that one jar requires; to do this, the jars are insulated from each other and from the earth; a wire from the outer coating of the first jar leads to the inner coating of the second, a wire from the outer coating of the second leads to the inner coating of the third, and so on, until the last jar is reached, the outer coating of which is in connection with the earth, and the inner coating of the first jar is brought into contact with the source of electricity. A battery arranged in this manner is termed a cascade battery, and a series of jars so connected is said to be charged by cascade. The thinner the glass in the jar the more electricity will it store; but care must be taken that the glass be not too thin, else

the two electricities will unite through the glass, and a hole will be left in the glass; in this condition, of course, the jar would be useless. If, however, the glass should be pierced and the tinfoil round the hole should be removed, the jar may then be used again.

Lane's Unit Jar.—To the left of Fig. 51 we observe a little apparatus, known under the name of Lane's unit jar. It serves the purpose of determining the quantity of the charge of the battery or the difference of potential

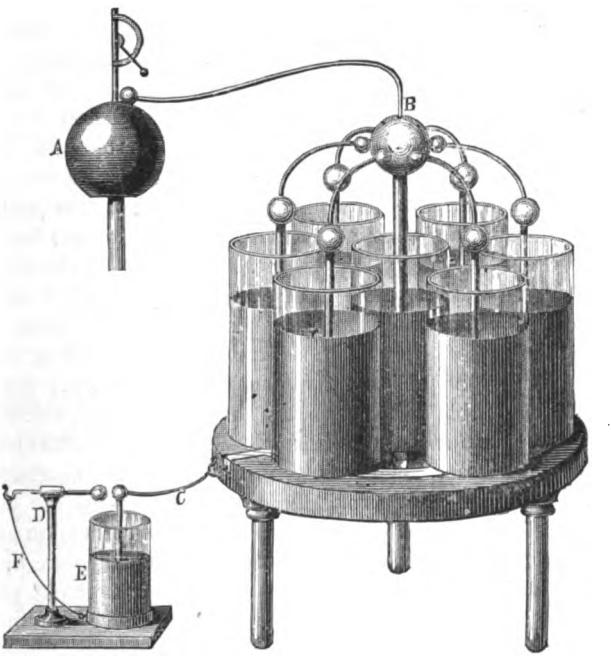


Fig. 51.—Battery of Jars.

between the coats. The distance through which a spark will pass when a conductor is brought near an electrified body is proportional to their difference of potential; it follows that when this distance remains the same, the number of sparks will enable us to determine approximately the quantity of electricity. This method of measurement has, however, the disadvantage that at the same time the battery is discharged, which may be avoided in the following manner: We know the induced electricity to be proportional to the inducing electricity. If now we make use of the induced electricity, which is as a rule conducted to the earth, for our measuring purposes, we are able to determine the quantity and potential without discharging the battery; this is exactly what Lane's unit jar is supposed to do. It consists of a small Leyden jar E, which rests on a conducting substance; close to it is the glass pillar D, fitted with a piece

of brass in which a horizontal brass rod slides; one end of this brass rod terminates in a little ball, the other end holds a small wire F, which is fastened to the conducting substance on which the jar rests. The wire C connects the inner coating of the little jar with the outer coatings of the battery. If now positive electricity from the conductor A of an electric machine is allowed to pass through to B, positive and negative electricity will be induced on the outer coating. The negatively induced electricity will be held on the inner side of the outer coating, the positively induced electricity will flow through the wire C to the inner coating of the measuring jar E. Here the process is exactly repeated; positive electricity is supplied to the inner coating, where again it will induce electricity, − and +; the + will flow to earth, but the − will spread through F over the horizontal brass rod and its ball. If the distance of the two balls in E has been properly adjusted, the jar will be discharged when the difference of potential of its coatings has the required value, and the two opposite electricities neutralise each other; the positively induced electricity of the battery is thus neutralised, so that there will be no connection with the earth when the battery has this measuring jar. If the distance between the two balls in E be kept constant, discharge will take place at one and the same difference of potential. The number of passing sparks will therefore indicate the quantity of the charge of the battery; dividing the number of sparks by the number of jars contained in the battery gives the quantity per jar. The unit thus obtained represents that amount of electricity which is necessary to cause *one* spark to pass. In this kind of measurement certain precautions are necessary. The battery must not be charged by allowing sparks to pass from the conductor. Before measurements are taken with the jar E, we must allow it to be charged and discharged once, on account of the residual charge which is left behind in Leyden jars after they are discharged.

Theory of the Condenser.—This will be a convenient place to collect the facts already explained respecting condensers. It has been mentioned that the capacity of a Leyden jar or other condenser depends—

1. On the size of the conducting coatings or surfaces.
2. On the thickness of the glass or dielectric.
3. On the "inductive capacity" of the dielectric.

Now if C be the capacity of any conductor, and if a quantity of electricity Q raise its potential by a difference V, then

$$Q = CV.$$

If without altering Q we diminish C, then we increase V. Now this is exactly what is done with Volta's condenser when duly charged and the upper plate be lifted off. The capacity is diminished, and the quantity Q having a higher potential manifests itself by the divergence of the leaves.

A condenser is a conductor in which, by the device of bringing near together two conducting surfaces oppositely charged, the capacity of the conducting

surfaces is increased without change of potential. Let us suppose the two surfaces to be spherical, and the dielectric simply air.

Call the surfaces M and N. Let their radii be a and b respectively. Suppose a charge, of which Q is the measure, to be imparted to M; it will induce on the inner side of N an equal negative charge $-$ Q, and to the outer side of N a charge $+$ Q will be repelled. This repelled charge is removed by contact with "earth."

Now the potential of the outer sphere is 0, because it is connected with the earth, which we assume to be at zero potential. Hence, the difference of potential between the centre and outer surface is,

$$\frac{Q}{b} - \frac{Q}{a}, \text{ or } Q\,\frac{a-b}{ab}.$$

But the capacity $\times$ difference of potential $=$ Q. Therefore by dividing both sides by Q we see that

$$\text{the capacity} \times \frac{a-b}{ab} = 1,$$

$$\text{and the capacity} = \frac{ab}{a-b}.$$

We see from this formula that the capacity of the condenser is proportional to the size of the metal globes, and that if the insulating layer is very thin, $a - b$ will be very small, and the value of the expression $\frac{ab}{a-b}$ will become very great. This proves the statement that the capacity of a condenser depends upon the thinness of the layer of the dielectric. Next consider the two modes of charging a number n of equal jars referred to above. If V be the potential of the machine and C the capacity of each jar, then the charge given to n jars, placed as in Fig. 51, is $(n\,C)\,V$: that is, n times the charge that can be given to one jar. In this case we increase the capacity n times by connecting all the outer coatings and also all the inner coatings. If we arrange them in series, each outer coating being connected with the next inner coating, we divide the whole fall of potential V into n steps. The difference of potential for the coatings of the same jar will be $\frac{V}{n}$. Hence the charge of this jar will be $\frac{V}{n}C$, and the charge of n jars V C, or the same as the charge of one jar. There is therefore no advantage in charging jars in series or by "cascade."

Determination of Specific Inductive Capacity.—Faraday determined the specific inductive capacities of a number of substances thus: He had two brass spheres, an inner and outer, so fitted that they were not in electrical connection, and that the space between them could be exhausted of air, or filled with any gas or substance that could be reduced to the liquid state. He had two of these condensers, A and B, exactly alike in all respects but one. In one condenser A the dielectric was air, and in the other B the space between the

two globes was filled with the substance to be tested. A was charged, and then the two knobs of A and B were brought into contact so that the charge was divided between them. The charges were then measured, and the ratio of that of B to that of A gave the inductive capacity of the dielectric used in B.

Hence, if C be the capacity of a condenser with air for dielectric, and K that of the same condenser with dielectric having a specific inductive capacity s, then

$$K = sC.$$

Another important difference has to be noticed between a condenser with a gaseous and one with a solid dielectric, namely, that the first is charged almost instantly, the second takes time. If the knob of a Leyden jar, or one plate of any condenser, be connected with an electric machine or generator, the other plate being in connection with the earth, a charge rushes in with great rapidity; but the entrance of the electricity does not instantly cease, as is the case with an air condenser. Similarly, when the two plates are joined by a wire so as to be brought to one potential, the electricity is discharged very rapidly at first; but this discharge does not then cease, and the electricity continues to flow out for precisely as long a time as it ran in, and with the same rapidity after equal intervals of time. If upon maintaining a difference of potential P between the coatings of the condenser, a quantity Q per second is found flowing into the condenser at the expiration of a certain time, say ten minutes, then ten minutes after the first discharge, the same quantity Q per second will be found flowing from one coating or plate to the other. The dielectric seems to absorb electricity at a certain rate when subjected to a certain difference of potential, and to yield it all up again at the same rate when the two plates are brought to the same potential.

ELECTRICAL DISCHARGE AND ITS EFFECTS.

General Phenomena connected with Discharge.—If we connect an electrified body by means of a wire with the earth, it loses all its electricity—that is, the electricity of the body flows through the wire to the earth, and is distributed over it, the earth being considerably larger than any other body. No matter how much electricity we may distribute over it, we cannot alter its electrical condition. We assume, therefore, the potential of the earth to be equal to o. When a body has a potential differing from that of the earth, and is connected with the earth by a wire, electricity flows along the wire from the higher potential to the lower. During discharge the electricity moves in the conducting wire; this motion we call current. The electricity flows until both bodies have the same potential. The discharge of a Leyden jar is slightly different. Here the connection is between two oppositely electrified surfaces, viz., the inner and the outer coating of the jar. The neutralisation of the two opposite electricities is brought about by the force of attraction. During discharge electricity flows through the connecting wire, not only in the direction from the inner to the outer

coating, but also from the outer to the inner coating; in this kind of discharge, then, we have a ***double*** current. But a double current is produced even when an electrified body is brought near an unelectrified one before connection. The moment we bring a wire near the electrified body a current is induced in the wire, the unlike electricities attract each other, and before the wire has reached the electrified body we see a spark pass. We see, then, that with each kind of discharge a spark passes. When the tension of the electricity on the two coatings has become sufficiently powerful to overcome the resistance of the air, discharge takes place spontaneously. The distance which the spark overleaps is called the sparking distance; this distance, of course, depends upon the difference of potential produced. That is to say, the tension of the electricity, or tendency to

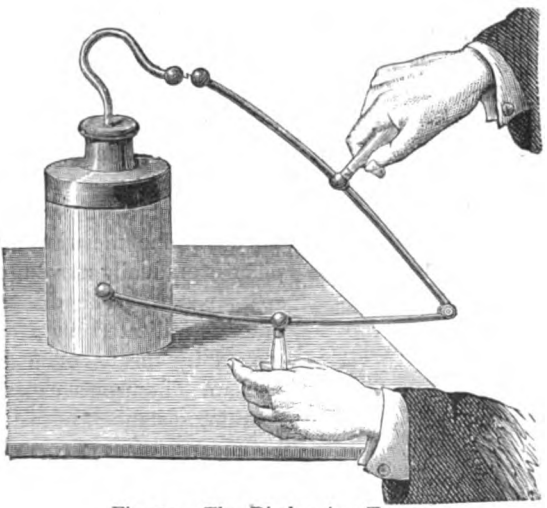


Fig. 52.—The Discharging Tongs.

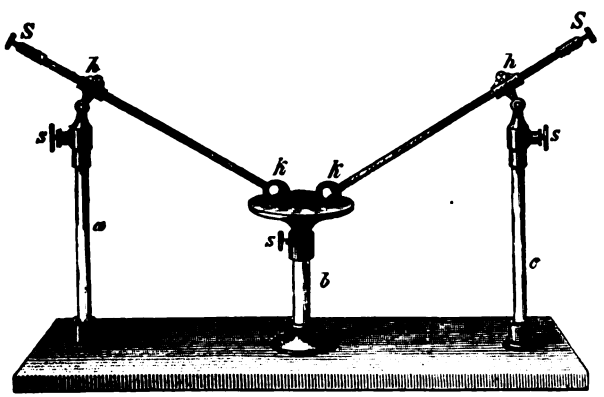


Fig. 53.—Henley's Discharger.

produce disruptive discharge through the air between two surfaces, is proportional to their difference of potential.

To discharge a Leyden jar, an apparatus as shown in Fig. 52 usually is employed. The outer coating of the jar is touched by one of the balls, the remaining ball approaches the knob of the jar until the spark passes over. If,

however, we wish to observe the effect of the discharge on interposed bodies, the apparatus represented in Fig. 53 will be found more convenient, where insulating handles s s direct, through slides and universal joints *h h*, supported by insulating pillars *a c*, the discharging knobs *k k*. The substance through which the discharge is to be passed is laid on the little table adjusted by the screw *s* on an insulating pillar *b*.

Sparking Distances.—To determine the sparking distance, the spark-micrometer, by Riess, is made use of. It is represented in Fig. 54. A is a heavy metal stand on which a metal plate is fastened horizontally; a glass pillar is fixed to one end of the plate, the other end has a slide, which is moved along by means of a screw; this slide carries another pillar. To determine the sparking distance, the slide with the pillar is gradually moved towards the fixed one until the spark passes. The distance of the two balls from each other is indicated by a scale along which the slide is moved by means of a fine well-finished screw. Sir William Thomson's experiments on the relation of the sparking distance to the difference of potential were made by means of two parallel plates connected with the quadrants of an electrometer. His experiments and those of Rijke agree in suggesting the conclusion that the sparking distance increases at a somewhat greater rate than the difference of potential of the discharging bodies. Rijke, who devoted much attention to the subject, found the law laid down by Riess not to be quite correct, and that the sparking distance increases more rapidly than the difference of potential between the sparking bodies. Rijke has given a formula for the calculation of the sparking distance from the potential, and the distances obtained thus, according to the formula, agree with actual observations better than those obtained from Riess's law, as will be seen from the following table:

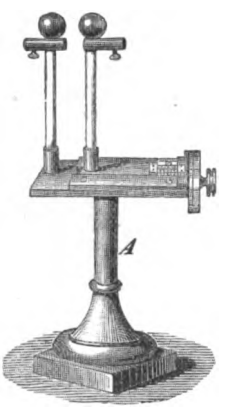


Fig. 54.—Riess's Spark Micrometer.

Sparking Distances in Distributors.	*Observed.*	*Potential calculated by*	
		Riess.	*Rijke.*
0·5	4·73	4·21	4·88
1·0	9·33	4·42	8·82
1·5	13·00	12·63	12·73
2·0	16·83	16·85	16·62
2·5	20·50	21·05	24·51
3·0	24·33	25·27	24·39
3·5	24·60	29·48	28·28
4·0	31·17	33·69	32·16

For small distances Rijke's calculations seem to be nearer the observed results. For longer distances Riess's are equally near. For the discharge of batteries, then, we may make use of Riess's law when the sparking distance

becomes very great, in which case it is proportional to the difference of potential. From this law it follows that the sparking distance must be independent of the nature of the circuit, and the correctness of this supposition has been proved experimentally. The density of the air, however, has to be taken into account; the sparking distance is lessened in denser air, and becomes greater when the atmospheric pressure is diminished. Not only the density, but also the chemical composition of the medium, influences the sparking distance. Faraday found the distances considerably less in chlorine gas, but twice as long in hydrogen gas as in air.

Effects accompanying Discharge.—An electric spark passes when two oppositely electrified bodies are brought near each other, and also when a non-electrified conductor is brought near an electrified body. Imagine two oppositely electrified bodies; for instance, brass balls suspended by threads from points near together. They will attract each other, and a spark will pass between them as soon as the sparking distance has been reached; both balls will then fall back to their vertical position, and by doing so indicate that the two conductors have been discharged. The electrical spark, then, might be explained as a neutralisation of the two electricities across the air. The violent shock which the particles of air receive during the discharge causes the effects of sound, light, and heat.

We have already stated that Leyden jars discharged in this manner do not lose all their electricity after the first discharge; a second spark may be obtained, and sometimes even a third, after the first discharge. The electricity left behind is called the *residual* charge. Riess, Fedderson, and others, found that the amount of residual charge which remains behind in the jar depends on the resistance in the circuit. This fact leads us to assume that the first discharge, too, must be considered as a series of partial discharges. The effect the resistance in the circuit has on the discharge is twofold: first, the time between two partial discharges becomes longer as the resistance increases; secondly, the greater the resistance, the sooner will it cause a discontinuation of the partial discharges.

Let us consider the first effect. When the first partial discharge has taken place, and the circuit is unelectrified, a second partial discharge can take place only when the difference of potential has reached the point to overcome the resistance of the air at the points of discharge in the circuit. It is evident that to obtain the required difference of potential more time will be required when the resistance is greater. It may happen that even after the first partial discharge so much of the electricity has been annihilated that the required potential cannot be produced by the remainder. At every discharge through air the particles of air are thrown aside, and the first spark must have left a kind of passage filled with rarefied air; in this manner the resistance at the distance of discharge will be lessened. If, therefore, the resistance be less, electricity will follow up quicker through the circuit than new particles of air will flow to fill the channel of rarefied air, and a second partial discharge will take place. As long as there is a moderate resistance, partial discharges will take place at longer

intervals, consequently the duration of the series of discharges constituting the first discharge will be prolonged. In our second case, let a great resistance be introduced into the circuit; we find in this case also the greater the resistance in the circuit the sooner must the partial discharges cease. The partial discharges may be lessened to such an extent that the duration of the series of discharges constituting the first discharge becomes less. The duration of a discharge depends, then, on the one hand, upon the time electricity requires to flow through the circuit after discharge; on the other hand, upon the time left to the particles of air to rush into the channel of rarefied air made by the spark. If the former case prevails, the duration of the discharge will be prolonged; if the second case prevails, the duration will be diminished. To prove this experimentally, both Fedderson and Wheatstone employed the same method. If a mirror rotates before any bright spot, a picture of that spot is reflected at each moment of rotation, and the image of the spot appears on the retina of the eye. Every sensation of light in the eye lasts a certain time; therefore, when the mirror rotates with such a speed that the time of a revolution is less than the time for which the impression on the retina lasts, one image succeeds another before the first has disappeared; we are then unable any longer to distinguish the separate images, and what we perceive seems a continuous line. If a mirror is allowed to rotate before the passing spark, it is evident that the duration of the time of light corresponds to the duration of the passing spark. The duration of the discharge is noted by taking account of the length of the reflected line and the velocity of the mirror. Now when the image formed by the rotating mirror is examined, it shows that, instead of a single spark, a discharge consists of a series of sparks, proving experimentally that a discharge consists of a series of partial discharges.

Fedderson met with discharges that seemed in some respects to contradict the observations here explained. He found that by lessening the resistance on the circuit up to a certain limit, the duration of discharge was no longer decreasing, but increasing. Fedderson calls the resistance at which the duration of the discharge begins again to increase the critical resistance, and explains the nature of this "oscillating" discharge in the following manner.

When the resistance in the circuit is less than the critical resistance, the electricities not only move up to the points of contact, but beyond them, just as when a pendulum is made to move it will not return to rest until it has made several oscillations. The smaller the resistance the pendulum has to encounter the longer it will oscillate. If friction and resistance could be reduced to nothing, the pendulum would move for ever. The same holds good in the case of these electrical discharges. The less the resistance in the circuit, the longer will the motion last. The motion would be perpetual if we were able to construct a circuit with no resistance; as every conductor has a certain power of resistance, the oscillations must come to an end. The number of oscillations therefore must decrease when the resistance in the circuit increases. No oscillations take place when the resistance increases beyond the critical resistance.

The oscillations are produced in the following manner :—A positively charged jar or battery has positive electricity transmitted to the outer coating, while negative electricity flows to the inner coating. The jar is discharged, and after this first discharge it will be oppositely electrified : that is, negatively charged. The further flow of electricity is therefore prevented for the moment by the force of repulsion ; after a short interval, again both kinds of electricity move in opposite directions : that is, positive electricity flows to the inner coating, negative electricity to the outer coating, and the second oscillation or discharge takes place, and so on until the surface is discharged. That these oscillations really take place has not only been theoretically deduced by Helmholtz, Kirchhoff, and Thomson, but proved experimentally by Oettingen Wüllner, who describes the experiment thus :

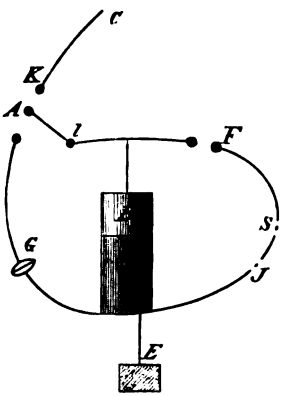


Fig. 55.—The Nature of the Residual Discharge.

Electricity was conducted to B, representing the battery in Fig. 55, through the wire C K, of which K could touch A ; at F in the circuit B F S J a spark micrometer was inserted, the sparking distance of which could be adjusted. The arm *l* A, movable about *l*, acted like a key, making contact either with K or the lower circuit, as desired. At the moment of discharge, the ball A, fastened to the wire *l* A, was pressed down so that the circuit B *l* G S was closed after the first discharge. In this circuit a discharge took place of the residual charge contained in the jar. The direction of the current of the positive electricities in this circuit indicated the kind of charge the battery possessed after the first discharge ; the direction of the current was indicated by the direction of the swing of the needle of a galvanometer inserted at G, and the amount of the discharged electricity was indicated by the needle's deflections. In this manner Oettingen was enabled to prove the existence of negative residual charges, as well as to show that when the resistance was not too great or the sparking distance not too small, the discharges, as a rule, were oscillating ones. Finally, it may be observed that Paalyow, by means of Geissler's tubes, made oscillating discharges visible. If the inner and outer coatings of a charged battery or jar are connected with a conductor, the one kind or other of discharge will take place according to the resistance in the circuit ; in neither case do we obtain a total discharge when the two coatings are in conducting connection. It has been observed that an electrical residue only remains when the insulator separating the two coatings is a rigid body, and that the amount of this residue depends upon the properties of this rigid insulator. It was further found that the residue increases with the thickness of the insulator, and the strength of the charges given to the coatings of the jar. From these facts we must conclude that the cause of these phenomena are the insulators. Faraday explained the phenomena of the electrical

residue in this way: When a jar receives a positive charge, + electricity flows from the inner coating to the surface of the insulator nearest this coating; — electricity flows from the outer coating again to the surface of the insulator nearest it. These opposite kinds of electricity, on the two sides of the insulator, attract one another. During discharge the electricities that remain behind on the coatings neutralise each other. The electricities on the surfaces of the insulator, however, are not able to flow back so quickly (on account of the bad conductivity of the insulator), and therefore remain behind after the first discharge; if after a

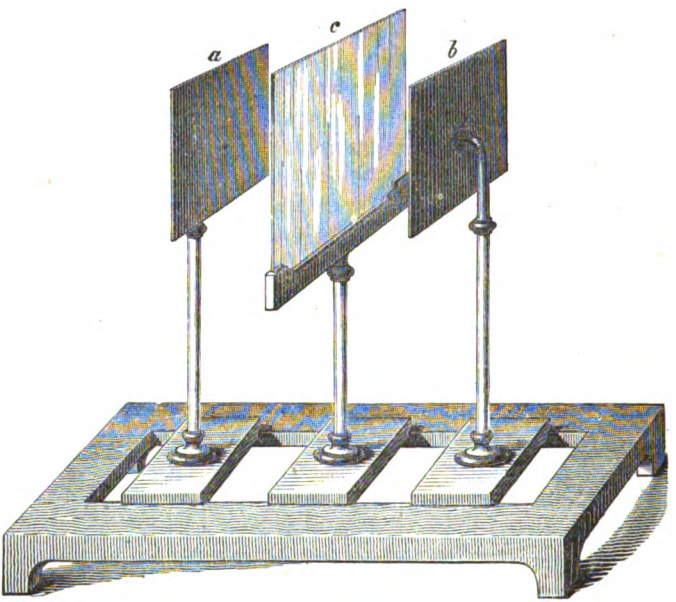


Fig. 56.—Condenser of Œpinus, with movable Coatings.

little while the coatings are again connected, the remaining electricities will have had time to flow back to the coatings, and a new discharge will take place. Maxwell attributes the residual charge not so much to the bad conductivity as the unequal conductivity of the dielectric. Others, by expanding Faraday's explanation, consider that the molecules of the dielectric are subjected to strain from which they do not recover all at once, so that the phenomenon resembles what is known as the "elastic recovery" of solids that have been subjected to a strain.

The Condenser with movable Coatings.—As a proof of this explanation a dissectible jar or plate was devised. The jar is first charged, then placed on an insulating table. The inner coating is lifted out, and the glass is taken out of the remaining coating. The two coatings may be rubbed or brought together, and yet when the parts are replaced, the jar will be found to be

charged. It seems as if the charges remained on the surfaces of the glass. A condenser which can be taken to pieces for this purpose is shown in Fig. 56. *a* and *b* are the two coatings, made of sheet brass, resting on movable glass pillars. The glass plate *c* represents the insulator. When *a* and *b* are pushed close to *c*, the apparatus becomes a Franklin plate; in this position the condenser is charged; when *a* and *b* are moved from *c*, both appear electrified, the one positively, the other negatively. The two plates are discharged, and again moved close to *c*; the plates again appear electrified, slightly weaker than before. It seems then that the greater portion of the charge resides within or on the surface of the glass plate. Kohlrausch objects to this explanation: for when both electricities really go over to the insulator, there is no reason why they should again go back to the coatings to cause a new discharge. Kohlrausch thinks the electrical residue to be an inductive phenomenon; he thinks the electricities on the coatings influence the insulator in the same manner as a magnet influences a piece of soft iron. Clausius is of the same opinion as Kohlrausch, whilst Bezold thinks Faraday's explanation to be more likely to be the right one. Wüllner tried experimentally to prove the correctness of the one or the other, but arrived at no definite conclusion. The more generally accepted view at present is Kohlrausch's theory that the electric induction produces strains and stresses, as described in page 65.

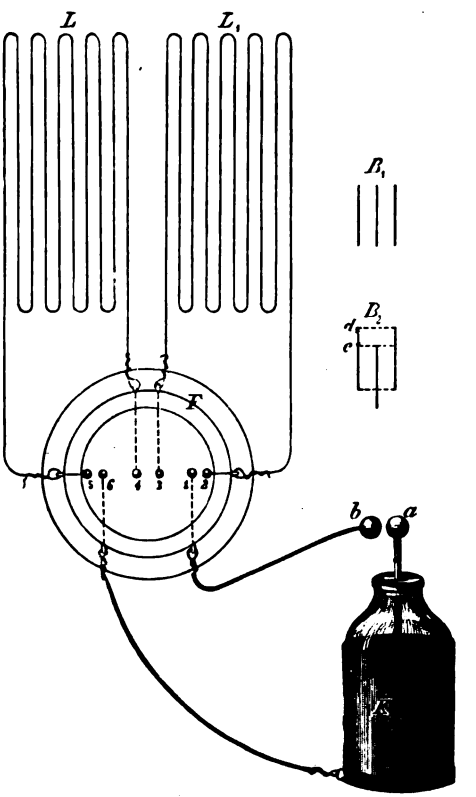


Fig. 57.—The Velocity of Electricity.

Velocity of Discharge.—Wheatstone's experiments regarding the duration of discharges led him to determine the velocity of the transmission of electricity. Le Monnier and Watson, as has been mentioned already, in the second half of the eighteenth century endeavoured to do so, but obtained no results. The method Wheatstone makes use of for the determination of the velocity of transmission is the same as for determining the duration of discharge, viz., a rotating mirror. The arrangement is shown in Fig. 57. K is a Leyden jar. The knob *a* is connected with the inner coating, and opposite to *a* is placed a

similar ball *b*, which is connected with the outer coating of the jar. Before the two electricities can unite, that is to say before a spark can pass, they have to pass through F and L L_1. If from the outer coating of the jar we trace the course of this, we find that electricity has to pass from 6 to 5, then through L up to 4, from there to 3, then through L_1 to 2 and 1, and finally through the wire to 6, and then back to *a* again. The electricity of the inner coating passes along the same course, but in the opposite direction. Wheatstone gave the insulated conductors L and L_1 a length of 402 metres, so that the total length the current had to travel was 804 metres. During discharge, sparks will pass between 5 and 6, 4 and 3, 1 and 2. The three sparks will appear in one straight line, the balls 1 to 6 lying in one straight line. Behind these balls a mirror rotates (not shown in the diagram). As long as the mirror remains motionless the three sparks will be seen as sparks simply; when the mirror rotates, the sparks appear as three straight lines parallel to each other.

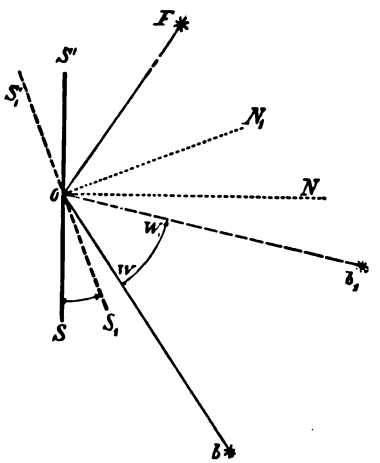


Fig. 58.—Double Angle of Reflection.

If the three sparks made their appearance at one and the same time (in other words, if electricity required no time to pass through L and L_1), the three lines in the revolving mirror would appear and disappear together; the appearance then would resemble B_1; but in reality B_2 is the appearance obtained in the experiment. From it we see that the spark passing from 3 to 4 must have been later than the sparks left and right of it. As the outer lines commenced and ended together, it follows, therefore, that the two outer sparks appeared together, that electricity requires a certain time to travel through the distances indicated in the figure, and also that during discharge there are two distinct currents opposite to each other, one flowing from the inner to the outer coating, the other in the opposite direction. The experiment enables us to calculate the velocity with which the electricity moves in the copper wires L. To pass from 5, through the circuit L_1 to 4, the current evidently required the same time as to pass between the first and second line in the mirror. This time we can determine if we know the velocity of rotation of the mirror and the length of the piece *d e*, which is the difference of the first and the middle line in B_2. Before making the calculation, it is necessary to mention that the image formed by reflection travels through twice the angle through which the mirror turns. Fig. 58 serves as an explanation of this fact respecting plane mirrors. S S′ represents a mirror, and O N the normal or perpendicular to it. F is the spark sending a ray of light in the direction F O. O *b* is the reflected ray, making the angle *b* O N = the angle F O N. If now the mirror be moved into the position S_1 S_1', so that the normal to it is O N_1, making with

the incident ray the angle F O N_1, the reflected ray must form an equal angle with the normal, and must therefore fall in the direction O b_1. The mirror has moved through the angle S S_1 while the reflected ray has moved through the angle W W_1. If we compare the two angles we find that W W_1 is double the angle S S_1. For the law of reflection shows us that:

In the first case, the angle F O b = twice the angle F O N.
In the second case, the angle F O b_1 = twice the angle F O N_1.
Hence, by subtraction, the angle b O b_1 = twice the angle N O N_1.

But the angle between the two normals = the angle between the two positions of the mirror.

Hence the angle b O b_1, or W W_1 = twice the angle S S_1.

As has been mentioned already, we do not perceive the images of the different sparks, but the distance which the spark travels seems a continued line of light, provided the mirror has a sufficiently great velocity. The length, then, of this line evidently depends upon the duration of the spark and the velocity of the mirror. We have seen that W W_1 describes an angle double the angle S S_1; the same holds good for the short line d e (Fig. 57), which is the difference between the middle and the outer line of light, and which we wish to determine. If we then know with what velocity the mirror moves, that is, if we know the time which is required to allow the mirror to make one revolution, and also the duration of the spark, we can calculate the length of the line d e. If, for instance, the mirror makes 800 revolutions per second, it travels through an angle of 800×360 degrees= 288,000 degrees. Let the time between the appearance of the first and second line of light = x seconds. The whole number of degrees the mirror goes through will be $x \times 288{,}000$ degrees. The image travels in the same time double the above distance, that is $2 \times 288{,}000 \times x = 576{,}000\,x$ degrees; this result represents the length of the piece d e (Fig. 57). Suppose the piece when measured proves to be 0·5 degree, we obtain $0{\cdot}5 = 576{,}000\,x$, from which we can easily find the value of x, the time of duration of the spark.

$$\text{Hence } x = \frac{0{\cdot}5}{576000} = {\cdot}000000868 \text{ second.}$$

The figures here given were obtained experimentally by Wheatstone. From these the velocity of electricity can be calculated. If the current requires 0·000000868 second to flow through the 402 metres of the circuit L, it will flow in one second through a copper wire the length of which is

$$\frac{402000000000}{868} = 463{,}133 \text{ kilometres.}$$

Hence, according to Wheatstone, electricity would flow through a copper wire 463,133 kilometres long in one second. The result obtained cannot be supposed

to give an exact, but only an approximate value of the velocity of transmission of electricity. That the properties of the conducting wire have to be taken into account has been mentioned in a previous chapter. Walker, Fizeau, and Grunelle arrived at different results. According to the theoretical calculations of Kirchhoff, as well as of Ayrton and Perry, the velocity of electricity in a wire without resistance would be equal to the velocity of light.

Heating Effects of Discharge.—We have yet to consider heating and lighting effects, as well as mechanical, chemical, magnetic, and physiological effects of the electrical discharge. The heating effect of the electrical spark is shown by means of the apparatus Fig. 59. The brass basin M rests on a glass pillar, and into M dips the point S, but without touching it. Into the basin, which is connected with the earth, inflammable substances, such as ether, alcohol,

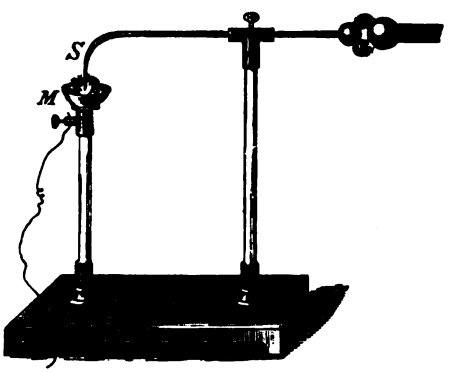


Fig. 59.—Heating Effect of Discharge.

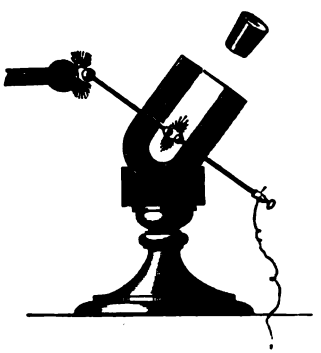


Fig. 60.—The Electric Mortar.

etc., are brought. The knob of a charged Leyden jar is brought near the ball at the other end of the rod S, when a spark will pass from S, and ignite the substance contained by the basin.

To ignite substances such as gunpowder, the universal discharger by Henley is made use of, shown in Fig. 53. The powder is placed between K K; and a wet string is introduced into the circuit to increase the resistance and to detain the discharge, as the powder requires some little time before it is sufficiently hot for explosion. Frequently, when discharge takes place immediately, the passing spark only scatters the powder without igniting it.

The heating effect of the electrical spark may be further shown by allowing it to pass through combustible gases. On this principle the electrical mortar is based (Fig. 60). The mortar is filled with some gas that forms an explosive with air, such as coal gas, mixed in explosive proportions. The mouth of the mortar is closed by a tightly fitting projectile. When the spark passes between the two balls, as shown in the figure, it ignites the gas, and the sudden increase of volume forces the projectile out of the mortar.

Riess invented an instrument to measure the heat caused by electrical discharges, shown in Fig. 61. The glass globe K, whose diameter is nine centimetres, has a platinum spiral terminating in the screws s s_1. A tube with a small but uniform bore, terminating in the vessel *g*, runs from the lower portion of the globe, as shown in the figure. B and G consist of wood, and can be raised or lowered about the hinge at the end by the metal prop adjusted by

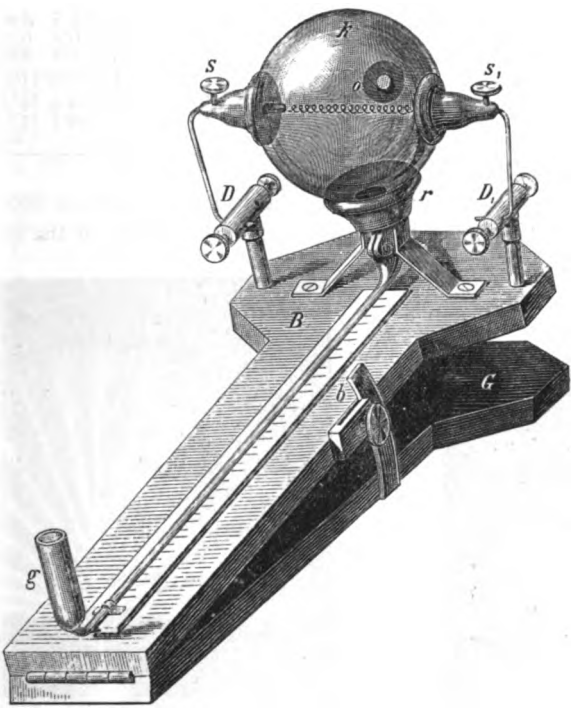


Fig. 61.—Riess's Electric Calorimeter.

means of the screw *b*. Thick wires connect the platinum spiral with the binding screws D D_1, which rest on glass blocks. At *o* the globe has a well-fitting glass stopper by which the atmospheric pressure can be regulated. When readings are taken, the glass tube is first filled with some fluid; the stopper *o* is replaced, and the whole instrument inserted in the circuit by means of D D_1. When the discharge has taken place the platinum wire becomes heated, and causes the air in the globe to expand, pushing the liquid in the tube towards *g*. By means of the depression in this tube we are able to determine the heating effects of an electrical discharge of a battery. In the following table are given the results of a series of experiments made by Riess:

NUMBER OF JARS.	2		3		4		5		6	
QUANTITY OF ELECTRICITY, Q.	DEPRESSION OF LIQUID IN TUBE.									
2	1·5	1·8								
3	4·3	4·0	3·0	2·6	2·0	2·0	1·5	1·6		
4	6·7	7·0	4·5	4·7	3·2	3·5	3·0	2·8	2·6	2·3
5	9·3	11·0	7·0	7·3	5·2	5·5	4·5	4·4	3·8	3·7
6	13·4	15·8	9·7	10·6	7·3	7·9	6·5	6·3	5·5	5·3
7			1·5	14·4	11·0	10·8	8·8	8·6	7·3	7·2
8			17·5	18·8	14·1	14·1	11·3	11·3	9·3	9·4
9					17·8	17·8	14·3	14·3	11·7	11·9
10							16·7	17·6	14·3	14·7

These tables show, then, that the heat in the platinum increases with the quantity of electricity, and is proportional to the square of the quantity of elec-

Fig. 62.—Brush Discharge.

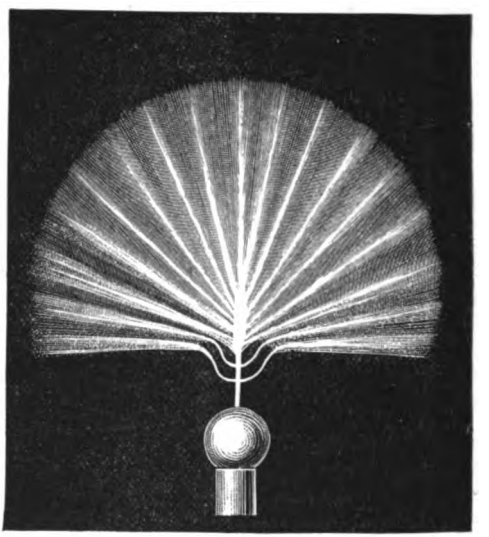


Fig. 63.—Brush Discharge.

tricity. If, for instance, we compare the figures obtained when experimenting with two jars, we obtain for the quantities of electricity 2 and 6 the proportion:

$$2^2 : 6^2 :: 1{\cdot}5 : 13{\cdot}4$$
$$\text{now, } 4 : 36 :: 1{\cdot}5 : 13{\cdot}5$$

Hence the number calculated from the law of proportion would be 13·5, and the observed number was 13·4. The agreement is so near as to prove the law.

Luminous Effects.—In close relation to the heating effects are the luminous effects caused by electrical discharges. If the potential of the positive conductor of an electrical machine becomes such as to cause an overflow of electricity, this flowing over causes the phenomenon of light, which may be seen to radiate like a brush when a point is placed on the conductor. The electrical brush represented in Fig. 62 is, however, only perceptible in the dark. If very powerful machines are used it assumes the appearance shown in Fig. 63. These phenomena of light undergo an alteration when a conducting substance is brought near the conductor of the machine (the distance must be so great as not to cause discharge); the brush of light then undergoes the modification shown in Fig. 64. When a powerful spark has to overleap a short distance only, it will appear uniformly luminous, and pass in a straight line. The same spark can be made to overleap several intervals in a circuit, provided the sum of the intervals is not greater than the interval the spark is capable of passing. On this principle the spangled tube, shown in Fig. 64, has been constructed. A glass tube has a strip of tinfoil wound in spiral form round it; the ends of the tinfoil are in connection with metal clamps, one of which is attached to the source of electricity, and the other to a wire connected with the earth. The tinfoil spiral is cut through at frequent intervals.

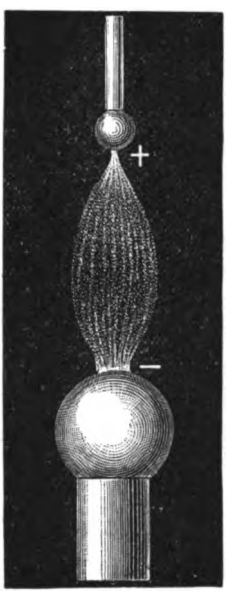


Fig. 64.
Spark Discharge.

Fig. 65.
The Spangled Tube.

If the distance the spark has to pass becomes very great, uniform luminosity and motion in a straight line cease. Powerful sparks overleaping a great distance have the appearance shown in Fig. 66. The ramification and zigzag motion of the spark may be explained in the following manner: The discharge always takes place along the line of least resistance. In consequence of the motion of the air and the heating effect, the air in front of the spark becomes considerably compressed, and thereby its resistance is increased. To avoid this resistance, it moves in a new direction until a certain density is again encountered, when the spark is again deflected, and so on. A spark passing between metals has been analysed

spectroscopically; and it has been found that the colour of the spark depends on the metals and the gas through which it passes. Properly speaking, the electrical spark is a consequence of the heating effect of the discharge, which renders particles of gas and metal incandescent. That particles of metal are really torn

Fig. 66.—The Zigzag Spark.

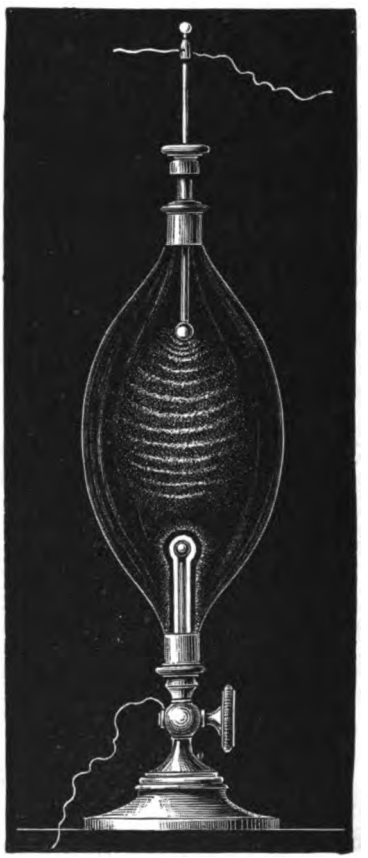


Fig. 67.—The Electric Egg.

off during discharge can easily be proved by examining the metal points between which the discharge takes place; metal particles are carried away from one and deposited on the other. If, for instance, two metals be taken, copper and silver, and the spark passes from the silver to the copper, a deposit of silver is found on the copper. To show the effect of sparks in different gases at different pressures the electric egg is used. (*See* Fig. 67.) It consists of a glass globe, shaped as represented in the figure; the brass fittings of the upper end have

an air-tight stuffing-box, or perforated cork, through which the electrode can be moved. The brass fittings at the lower end carry the second electrode, which, as a rule, is fixed. The lower portion of the foot is accurately ground, so as to fit tightly on the plate of an air-pump. By means of a stop-cock the pressure can be regulated, or the egg closed when the desired degree of exhaustion has been attained.

Let us take an actual example for illustration. Suppose the globe to be filled with dry ordinary air, or with pure nitrogen gas, the electrodes being arranged at such a distance that no spark will pass; a portion of the air is now removed by means of the air-pumps. As soon as the air has been rarefied to a certain degree, red lines of light will appear at the positive electrode; as the exhaustion is continued, the number of lines of light increases, and the glow grows in size until the whole globe is filled with one mass of red light, brightest towards the positive electrode and diminishing in luminosity towards the negative electrode. Frequently layers of different intensity appear, as shown in Fig. 67. Different colours are obtained with different gases.

Fig. 68.—The Electric Hail.

Mechanical Effects. — To the simplest mechanical effects belong the electrical wheel or windmill already referred to, the motion of which is due to the force of repulsion between points and particles of air. When we place the electrical wheel under the receiver of an air-pump, and then charge it after the air has been exhausted, we find that it rotates far more slowly than before. The phenomena of attraction and repulsion have been made use of for electrical toys, as, for instance, the electrical butterfly, electrical hammer, etc., etc., the principle of which will be understood from the following description of one, namely, the electrical hail. Several cork and pith balls are placed on a metal plate which is connected with the earth. A bell-jar, through the neck of which there passes a brass rod terminated by balls, covers the whole (Fig. 68). The inner ball becomes electrified when the outer is charged, and attracts the cork balls, electrifies them, and then again repels them. The electrified cork balls fall upon the metal plate, lose their electricity, and are again attracted by the brass ball. The cork balls continue to jump about until the charge in the brass ball has nearly spent itself.

Fuchs observed that when water drops are electrified they become larger, and the relationship between the size of the rain-drops and the electrical condition of the atmosphere deserves the attention of physicists.

In the history of electricity we mentioned an experiment that served to

support Dufay and Symmer's theory: we mean the perforation of a stout piece of paper by means of the electrical spark. The turning up of the edges on both sides was accounted for by stating, that an electrical discharge was the result of two currents flowing in opposite directions to each other. Riess, however, holds that the experiment only proves that the mechanical effects produced by the current spread uniformly in all directions, and the fibres of the paper give way in that direction where they find least resistance. If the electrical discharge is sufficiently powerful, it will perforate glass plates of considerable thickness. The apparatus usually used for this purpose is shown in Fig. 69. In the centre of a cylindrical glass vessel is a metal point *a*, which is connected with the binding screw K, to which a wire can be attached; exactly opposite to *a* is the point *b*. The glass plate S S to be perforated is placed between the two points, resting on the top of the cylinder. Care ought to be taken that the glass plate is dry and clean, and not too small.

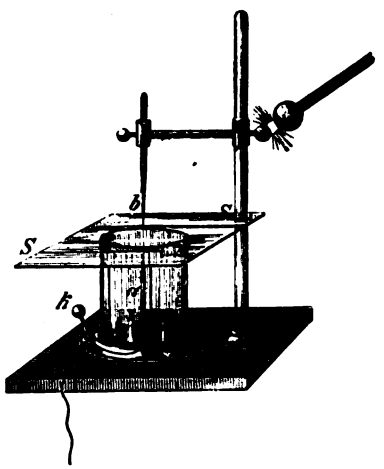


Fig. 69.—The Perforation of Glass.

Electric Dust Figures.—Lichtenberg's figures are another illustration of the mechanical effects of electrical discharges. These figures are obtained in the following manner: Over a smooth cake of resin is held an iron point connected with the inner coating of a Leyden jar or the prime conductor of an electric machine. Through this point the resin cake receives its charge. The metal point is withdrawn, and a fine powder is dusted through a piece of muslin over the cake. The dust then arranges itself in distinct figures. The mixture usually taken consists of vermilion and sulphur, or red lead and lycopodium powder, and is shaken out from a muslin bag. The particles rub against each other and against the muslin and become electrified, the sulphur negatively and the vermilion positively. The former are attracted by the positively electrified parts of the resin cake, the latter by the negative. The positively electrified places will appear yellow, and the negatively electrified places red. But the difference of form is of more importance than this difference of colour. Fig. 70 shows the characteristic figure for a positive charge; Fig. 71 the same for a negative charge. If the resin cake has a mixed charge—that is, positive and negative—we obtain a mixed figure. Fig. 72 represents such a figure. We observe a red disc in the centre, corresponding to the negative electrification, surrounded by rays of yellow, corresponding to the positive electrification. Such a figure is easiest produced by a Ruhmkorff coil. The investigation of Lichtenberg's figures has been continued by Bezold, Reitlinger, Riess, and Wächter. Wächter especially made

experiments under many conditions, and he succeeded in obtaining positive figures which had the appearance of negative ones; this, however, only happened when the point through which the charge was directed was made of a non-conducting substance, having its surface free from dust; but he never obtained negative figures resembling positive ones. From these experiments Reitlinger and Wächter concluded that for the production of positive figures the carriers of electricity must be rigid particles, which from the point are hurled towards the surface on which they slide, and to which they give up their electricity. When a spark passes between metals, little particles of this metal are torn off, as has been already mentioned. Now it is these torn off particles that cause

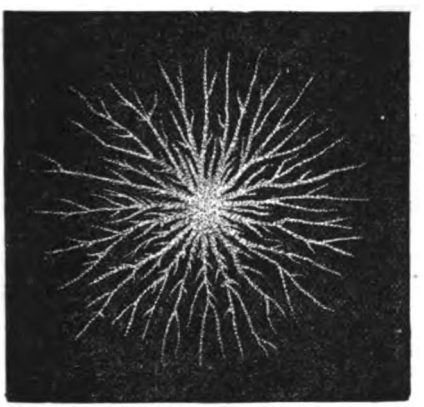


Fig. 70.—Positive Dust-Figure.

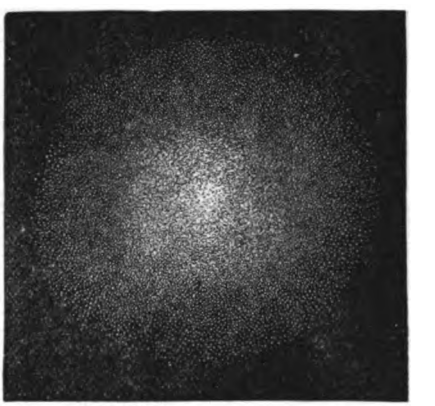


Fig. 71.—Negative Dust-Figure.

the ramification in the positive figures, for if a non-conductor be used, such as a piece of wood, the tearing off of the particles does not take place, and the figure is simply a round disc. Electrification of the resin plate in this case is obtained through the agency of particles of air, which electrify the plate uniformly in all directions. If, however, the surface of the bad conductor be covered with dust, this dust will be hurled away by a positive discharge, and the positive figure will then show the ramifications in spite of the conducting substance being used. Wherever negative electricity is imparted to the resin surface, traces of *disc*-shaped distribution are left behind; whilst positive electricity produces figures which may appear, according to circumstances, in radial lines, or in circular discs and rings. To produce a negative figure with even the slightest trace of lines has been found impossible.

For the production of Lichtenberg's figures we may not only use resin plates, but also glass, ebonite, wax, etc. The powder, too, may be changed for others, provided one of the ingredients becomes positively electrified, the other negatively electrified, when rubbed against the muslin bag.

Physiological and Chemical Effects of Electrical Discharges.—When we bring a finger near to a charged conductor we feel an unpleasant sensation, and if the spark is powerful serious injuries may be received. The spark of a battery of Leyden jars is capable of killing large animals.

When the discharge of a battery is conducted through chemical compounds, they may be decomposed. For instance, if from the negative and positive conductors of an electrical machine wires are dipped into a solution of sulphate of copper, and the machine is worked for some time, we shall find on the wire of the negative conductor metallic copper deposited, although the action is a very slow one. The peculiar odour in the air about an acting electric machine is also due to the chemical effects of electrical discharges; the atoms of oxygen are decomposed and rearranged in a modification known under the name of ozone.

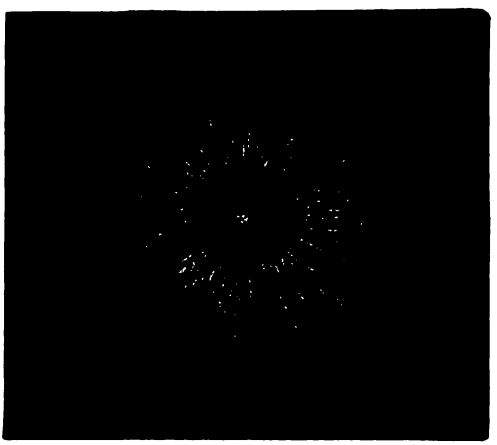


Fig. 72.—Mixed Dust-Figure.

Magnetic Effects.—Magnetic effects of electrical discharges show themselves in two different ways. A magnetic needle free to move is influenced when brought near a circuit through which discharges take place. When electrical discharges are conducted through a wire spiral, in the centre of which there is a steel needle, this needle will become a permanent magnet.

The Return Shock.—Many electrical effects of discharges are to be accounted for as effects of induction. The return shock sometimes felt by persons standing near a conductor which is being discharged is of this nature, and may be explained in this manner. Two conductors are placed near to the points between which the discharge is to take place; the one farthest from the circuit being connected with the earth. Before the neutralisation of the two electricities in the circuit, the two conductors will be influenced by them. The positive and negative induced electricities remain separated from each other until discharge in the circuit has taken place; after that the separating force loses its power, and the two electricities unite again; the two conductors have another discharge, which is called the return shock, and which is most noticeable in that connected with the earth. This return shock is also the cause of the motion in a frog's leg when near an electrical machine from which sparks pass. Persons standing close to a circuit through which powerful discharges are passed may feel a shock, although in no way connected with the

circuit. Here, too, the two electricities in the human body are separated by the induction of the charged conductor near it, one kind being attracted, the other driven to earth; the uniting of these again after discharge constituting the return or after shock.

Atmospheric Electricity.—The upper layers of air are more or less electrified, so as to have a potential differing from that of the earth, but how their electrical condition has been produced is not at present known. Condensation of water-vapour is supposed to produce electricity; chiefly, perhaps, because greater differences of electrical condition at different elevations are to be found under a clouded sky than with a clear sky, and it is always clouded when it lightens. Lamont considers the atmospheric electricity to be a consequence of the earth's electricity. Close to the earth the air has little or no electricity; the farther from the earth the greater the amount of electricity in the air.

Difference of Potential in the Air.—Employing the terms we have now adopted to indicate a difference of electrical condition, we should say that many experiments prove that there is a difference of potential between the earth and points in the air above. In fine weather the potential is higher the higher we go, increasing usually at the rate of twenty to forty volts for each foot. It changes, however, very rapidly in broken, windy, and rainy weather, and is even at times reversed, becoming for a time negative as regards the earth. The plans adopted to test the potential at any point usually consist in placing an insulated conductor at that point, and allowing for the discharge of free electricity from it, its electrical condition being afterwards tested by an electroscope or electrometer. This discharge takes place when material particles are made to leave the conductor. Volta used a small flame at the end of an exploring rod. Sir William Thomson used an insulated water-can, from which water was allowed to drip, or an exploring rod with smouldering touch-paper at the end. He has also employed with success a portable electrometer, on the same general principle as the quadrant or divided ring electrometer. Peltier used an insulated pith-ball electrometer with a metal dome, and means of connecting it for an instant with the earth.

Lightning.—Lightning is the equalisation of potential in the clouds, where the electrical spark appears as lightning and the sound it produces as thunder. Lightning chooses the best conductor for its passage. There are three forms of lightning: fork lightning, sheet lightning, ball lightning. Sheet lightning may be regarded as brush-like discharges from cloud to cloud; it is not necessary that one of the clouds should have positive and the other negative electricity. As we can draw sparks from an electrified body by bringing near it an unelectrified body, so an electrified cloud can lose its electricity to a non-electrified cloud. Fork lightning may be compared to the spark with ramifications: and the same explanation may be given of it. The quantity of electricity in a cloud depends on its capacity and potential; if the capacity diminishes while the quantity remains the same, the potential rises. The difference of potential between two

masses of cloud, or between one mass of cloud and the earth, may become so great by the coalescing of drops and consequent reduction of capacity, that the intervening air gives way under the strain, and a flash of lightning is the result. When lightning is directed towards our earth, it strikes the highest points first, such as towers, trees, etc., and then takes that path to earth which offers least resistance to its passage. If lightning has to pass through dry sand, it fuses it, and produces what is known as "fulgurite." Ball lightning, a phenomenon

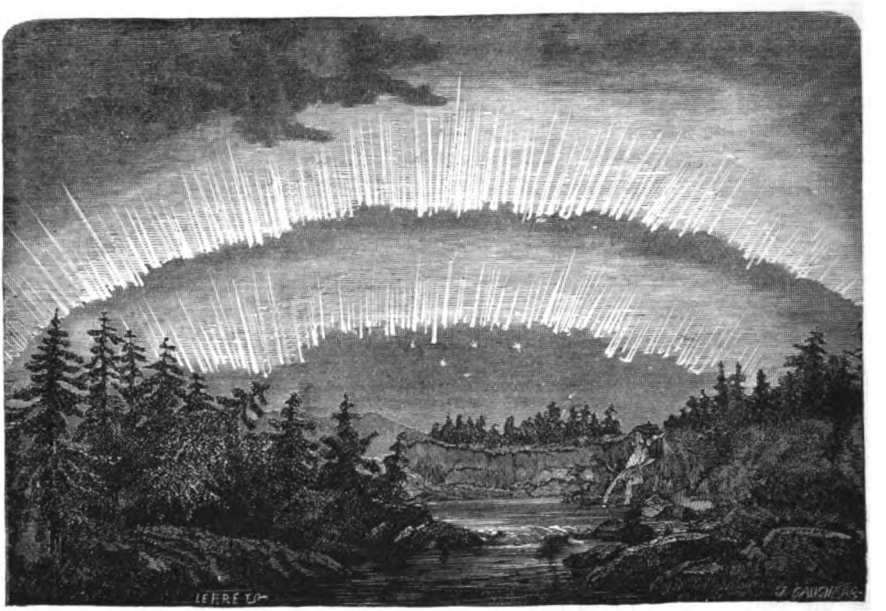


Fig. 73.—The Aurora Borealis.

not very frequently met with, consists of balls of fire visible for about ten seconds, and then bursting with a loud explosion. Lightning without thunder may be the reflection of a far distant thunderstorm, or the quiet flowing out of electricity from the clouds. The St. Elmo's fire shows itself in brush-like little flames, appearing on the sharp edges or points of different bodies when the air is rich in electricity. Often a peculiar noise which is characteristic of the flow of electricity from points, is heard when the brushes are seen. Lightning often covers a distance of more than 1,000 metres; owing to the rapidity with which lightning travels through the air we see the whole distance illuminated. The time which elapses between the flash of lightning and the accompanying thunder serves often to approximately determine the distance of a thunderstorm. Light from such a distance reaches us almost immediately; sound

travels 333 metres per second. The thunderstorm, therefore, will be at a distance of 333 metres (370 yards) × by the number of seconds that have elapsed between the flash and the report.

The Aurora Borealis.—This phenomenon is seen in the polar regions every night, in some latitudes seldom, and in the regions of the equator never. In the intermediate latitudes hardly more than a reddening of the evening sky is seen; but in the polar regions it is one of the most brilliant phenomena. Although the nature of the aurora borealis as yet is little understood, it seems clear that magnetic storms, or disturbances of the earth's magnetism, are due to the same cause, as they always occur together. There are many points of similarity between a discharge of electricity through tubes of rarefied air and the auroral phenomenon. Franklin explained the aurora as an electric discharge in the rarefied atmosphere of the upper regions, between the cold air of the polar regions and the warmer air from the tropics. The rarefied air is nearer the earth at the poles than the equator, in consequence of the earth's centrifugal motion, and the earth being negatively electrified, negative electricity will flow from this point, directed against the positively electrified upper layers of rarefied air.

THE GALVANIC CURRENT.

Generation of Electricity by contact between Metals or between Metals and Fluids.—Let us refer again to the flow of electricity in the discharge of a Leyden jar, connected with a unit jar in the following manner. A wire leads from the outer coating of Lane's unit jar to a brass ball, which stands at a convenient sparking distance from the second brass ball connected with the inner coating. A neutralisation of the two electricities will then take place. To produce the neutralisation spark, electricity from the inner coating had to flow to one ball, while opposite electricity from the outer coating had to reach the second ball. The two electricities then move in opposite directions, as has been mentioned; motion of electricities in the circuit is not at an end as soon as the electricities have arrived at the points of disconnection, but electricity of the outer coating moves on until it reaches the inner coating, and *vice versâ*, as was shown in the explanation of oscillating discharges (page 77). We have had, further, under examination the chemical, mechanical, and physiological effects produced by electrical discharges, and we have seen that to produce these effects electricity had to be in motion, and to flow through wires. We have now to trace the same effects when two dissimilar metals are placed in an acid liquid, and are connected by a wire. Such an arrangement is called a galvanic element (Fig. 74). The simplest form of a galvanic element consists of a plate of zinc and a plate of copper immersed in diluted sulphuric acid. The element is said to be closed when the connecting wires touch each other, open when the wires do not touch each other. When the circuit is closed we say a current flows through it, meaning thereby that the following effects may

be observed: (1) If the wire be stretched over a magnetic needle, the needle will be deflected; (2) if the wire be broken and the two ends be placed upon moist paper which has a solution of potassium iodide and starch, the paper will become blue, owing to the separation of iodine; moreover, the two ends placed upon the tongue will produce a peculiar taste; (3) a thin wire inserted will become slightly hot. The current here also, therefore, may be made to produce all the magnetic, chemical, and physiological effects we have described in connection with the flow or discharge of electricity. If we examine the electrical nature of the two metals more closely (when they are partly immersed, but not connected by an outside wire) we find that the zinc end *not* immersed is negatively electrified, and the dry copper end positively electrified. Hence, when the circuit is completed, from the zinc end negative electricity flows to the copper, and from the free copper end positive electricity flows to the zinc. From these facts we conclude that electricity must be in motion not only through the connecting wire, but also between the immersed ends of the metals in the liquid. Before the zinc and copper plates were immersed, both electricities were equally distributed over them; as soon as they are immersed in the liquid the equilibrium is disturbed, and the two electricities which previously neutralised one another on both plates become separated from each other, negative electricity collecting at the free end of the zinc, positive at the free end of the copper. Hence, when the plates are joined by a wire it follows that positive electricity flows from the immersed zinc end through the fluid to the copper in the fluid. Positive electricity flows, then, in the cell from zinc to copper, out of it from copper to zinc. Before the partially immersed plates are connected by a wire, on being tested by an electrometer they are found to have a difference of potential, the free end of the copper having a higher potential than the free end of the zinc. Hence we speak of the current that is set up when the connection is made as having a direction in the connecting wire from the copper to the zinc. The strength of the current may be estimated by means of any one of the effects already described.

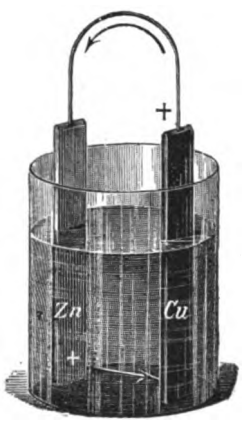


Fig. 74.—The Galvanic Element.

An instrument for measuring the strength of the current by means of its action on a magnetic needle is called a *galvanometer.*

An instrument for measuring the strength of the current by means of the chemical action it sets up is called a *voltameter.*

An instrument for measuring the difference of potential between any two parts of the circuit is, as we have already seen, an *electrometer.*

Instruments on the same principle as a galvanometer, but intended simply to indicate the direction of the current without measuring its strength, are

sometimes called *galvanoscopes*, just as the instruments for revealing the nature of a statical charge without measuring it are called electroscopes.

Theories regarding the Generation of Electricity.—When we ask for the cause of these phenomena, we find that two explanations or theories have prevailed. According to the one longest maintained, the generation of electricity is to be explained by the mere contact of bodies with each other; according to the other, chemical processes are the cause of the electrical current. The former is called the contact theory, the latter the chemical theory.

The Contact Theory.—The contact theory was established by Volta's fundamental experiment, and led to the scientific war that raged towards the latter end of the eighteenth century between Volta and Galvani and their followers. Galvani attributed the motions of the frog's leg to animal electricity; Volta, on the contrary, to metallic electricity; that is, to electricity generated by contact of two metals. According to this idea, the frog's leg is but a sensitive electroscope. Volta's so-called fundamental experiment may be made in the following manner: Two metal discs, one of copper, the other of zinc, perfectly smooth on their surfaces, are insulated by means of glass handles. The copper and the zinc are placed in contact, and then separated by means of the handles. It is then found that the two plates possess opposite electricity; when tested, the zinc appears positively electrified, the copper negatively. The copper becomes negatively electrified when touched with a tin or iron plate, but becomes positively electrified when touched with silver or platinum. It has been found that whatever metals are brought into contact with each other, they show, when separated, opposite electrification; during the contact, then, a force must cause the neutral electricities in the two metals to separate, one passing over to one metal and the other to the other metal. The force which causes this motion or current is called electromotive force; the metals themselves being termed electromotors. The cause of the electromotive force, Helmholtz thinks, is to be sought in the difference of the force of attraction each metal possesses for electricity. The matter of the metal attracts the two electricities, and this attraction differs in strength according to the kind of electricity. Electromotive force acts in the same manner as molecular forces act, that is, at immeasurable small distances, whilst the electricities influence each other from finite distances. The following example will show how the two electricities may be separated from each other by the differing force of attraction of different metals. Let us assume that negative electricity is attracted more strongly by the copper, the positive electricity more strongly by the zinc. As long as the two plates do not touch each other the force of attraction is not called upon to act, as the two electricities are equally distributed over the plates. As soon as the metals touch each other, however, on account of the different force of attraction of the two metals the equilibrium between the electricities will be disturbed. As the forces of attraction are only capable of influencing the electricity at very short distances, the electrical equilibrium will only be disturbed where the copper and zinc actually touch. At the place of contact two different forces

are called into action, viz., the force of attraction between the two opposite electricities, and the different forces of attraction of the two metals; and electrical equilibrium is only possible when the resultants of these two forces are equal to each other.

Let us first consider what takes place on the zinc plate. Equal quantities of positive and negative electricity are equally distributed over it; in other words, the plate is unelectrified. Now we allow the copper to touch the zinc plate. The negative electricity, as before, is attracted by the positive electricity; and it is also attracted by the zinc and copper plates, but less strongly by the former than by the latter. It follows that negative electricity must flow from

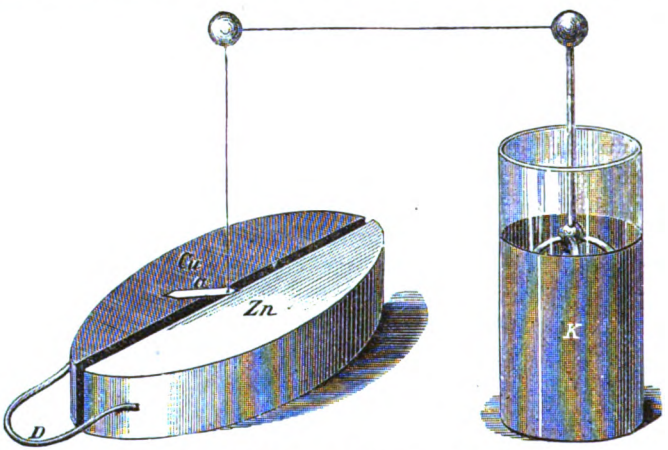


Fig. 75.—Different Potential in two Metals.

the zinc plate to the copper plate if equilibrium is to be restored. Again, the two electricities of the copper plate were also in equilibrium before contact. After contact, in consequence of the stronger force of attraction of the zinc plate for positive electricity, a portion of it must flow over to the zinc plate; therefore the result of the contact of the two metals is a flowing over of positive electricity from the copper to the zinc, and a flowing over of negative electricity from zinc to copper. Here, then, is a galvanic current of short duration, which ceases as soon as equilibrium between the forces is restored. When the two plates are separated, it is evident that the copper plate will have a positive and the zinc plate a negative electrical charge. In other words, the plates have a difference of potential. To prove that it really is so, Sir W. Thomson has devised the following experiment with an apparatus on the principle of his electrometer (Fig. 75). The aluminium strip *a*, which we will call the needle, is suspended from a flexible wire in connection with a Leyden jar K. Under the needle two plates (one of copper, the other of zinc) are arranged horizontally so that there is a small distance between the two, this space being

parallel with the needle when in its normal position. When the jar is highly charged the needle will have a high potential, and influence the two plates. For instance, if *a* is positively electrified, the induced negative electricity will come to the surface of the two plates. On account of the symmetrical position which *a* has relatively to the two plates, they will have the same potential, and attract *a* equally, consequently *a* will remain exactly midway between the plates. If now we connect the copper plate with the zinc plate by means of a wire D, the different forces of attraction of the two metals will come into action. As we have explained, negative electricity flows from the zinc plate to the copper plate, and positive electricity flows from the copper plate through the wire D to the zinc plate. The result obtained by connecting the two plates will therefore be that the copper plate becomes more strongly electrified negatively, and more weakly positively, than the zinc plate. The zinc will have the more + electricity, the copper the more − electricity, and the difference will influence the position of *a*. The aluminium needle, being positively electrified, will be attracted most by the copper and repelled most by the zinc plate. The needle, therefore, leaves its position, and moves towards the copper plate.

It may be useful to point out, that although in the contact series the copper is negative in relation to the zinc, and the zinc positive in relation to the copper, yet in the galvanic cell represented in Fig 74, we call the copper the positive plate and the zinc the negative plate. The reason for this will be seen by breaking the copper wire joining the two plates. The origin of the difference of potential will be at the junction of the piece of wire left in the zinc. This wire will have negative electricity, while the zinc, the copper, and the copper wire on the right will have positive. Hence, positive electricity, according to the contact theory, will flow from the zinc through the liquid to the copper, and from the copper through the wire to the zinc.

The Chemical Theory.—A short time after Volta's experiments had become known, another explanation of the production of galvanic electricity was brought forward. According to this mode of explanation, galvanic electricity can only be produced by chemical action. Both the chemical and contact theory found disciples, and even at the present time both are maintained. Advocates of the contact theory were Volta, Téclet, Gassiot, Thomson, Hankel, Kohlrausch, and others, whilst Faraday and De la Rive maintained the chemical theory.

When a piece of zinc and a piece of copper are immersed in diluted sulphuric acid, we soon observe gas bubbles rising out of the liquid at the copper plate; and further, the zinc loses in weight. The liquid itself no longer consists of diluted sulphuric acid alone, but contains zinc sulphate. The chemical energy of the zinc and sulphuric acid is lost. They cannot be again separated, unless energy be expended for the purpose; hence, their potential energy of separation has disappeared. But as we can neither destroy nor create energy, this chemical energy must appear in some other form. Here it appears

in part in the form of heat, for the liquid during the formation of sulphate of zinc becomes warm. If the electrical properties of the metal and the liquid be examined, we find them oppositely electrified. This condition, too, is to be set down as one of the consequences of the change of the chemical energy. This explanation of the generation of the galvanic current in no way contradicts the law of the conservation of energy, and this is what the followers of the chemical theory object to in the contact theory. They say, by the mere contact of two metals no work is done. The energy of the electrical current, would be generated out of nothing, which is impossible. Whenever a galvanic current is generated by immersing different metals in a fluid, we cannot help noticing such chemical processes, which seem to favour the chemical theory. But how are we to make Volta's fundamental experiment agree with the chemical theory? We must not overlook the facts that the most sensitive apparatus has to be employed if the experiment is at all to succeed; that at the surface of every body gases condense, and that this layer or coating of gas is exceedingly difficult to remove. It has been remarked that the difference of potentials between a metal and the air that surrounds it is proportional to the tendency of the metal to become oxidised by the air. The followers of the chemical theory, therefore, say, Volta's fundamental experiment has nothing to do with two metals in contact, but two metals separated from each other by a layer of moisture or of gas. This layer, although only very thin, is sufficient to start a chemical action, and the thinness of it accounts for the scanty amount of electricity generated by this experiment. The theory that chemical action is the cause of the generation of electricity seems to find the more confirmation when we take into consideration that greater quantities of electricity are generated by contact of metals with fluids.*

It is possible that up to a certain point both parties are in the right. The process may take place in such a manner that whenever the metals are brought to touch each other their electrical potentials are changed; that is to say, a distinct statical condition is produced, whereby no kind of motion is required, and the work necessary to bring the two bodies into contact with each other is sufficient to produce this statical condition. This explanation would not stand in opposition to the law of conservation of energy. The difference of electrical potential in the bodies becomes then the cause of a chemical process which is continuous. In this manner a lasting galvanic current may be produced. Cause and effect now strengthen each other, just as during combustion temperature is increased by oxidation, and the high temperature facilitates oxidation.

* The chemical explanation of Volta's fundamental experiment found a warm advocate in Franz Exner, in Vienna. Numerous experiments led him to believe that the generation of electricity by contact of two metals is due to the surface oxidation of the metals. During this chemical process the metal becomes negatively, the oxide layer positively, charged, and the latter, being an insulator, retains its electricity. If now the oxidised plate is touched with a clean metallic plate, the positive electricity of the oxide layer induces electricity on the clean metal plate. Volta's fundamental experiment, according to this explanation, would have to be considered an induction phenomenon.

Motion of electricity (that is, the galvanic current) is due, then, to a chemical process, but the original generation of the difference of electrical potential initiative of the chemical process is due to the contact of metals.

Volta's Contact Law.—When metals differing from each other are brought into contact, we obtain different results both as to the kind of electricity generated, as well as the difference of potentials. Volta found that iron, when in contact with zinc, becomes negatively electrified; the same takes place, but somewhat weaker, when iron is touched with lead or tin. When, however, iron is touched by copper or silver, it becomes positively electrified. Volta, Seebeck, Pfaff, and others, have investigated the behaviour of many metals and alloys when in contact with each other. The following lists are so arranged that those metals first on the list become positively electrified when touched by any taking rank after them:

According to Volta.	*According to Pfaff* (1837).
+ Zinc	+ zinc
lead	cadmium
tin	tin
iron	lead
copper	tungsten
silver	iron
gold	bismuth
graphite	antimony
manganese ore.	copper
	silver
	gold
	uranium
	tellurium
	platinum
	palladium.

Volta laid down the following law regarding the position of the metals in his table. The electrical difference of two metals in the table is equal to the sum of electrical differences of all intermediate ones. When Volta measured the different electrical differences between the respective metals, he found:

				Difference Value.	
Between	zinc	and	lead	5	
,,	lead	,,	tin	1	
,,	tin	,,	iron	3	
,,	iron	,,	copper	2	
,,	copper	,,	silver	1	
,,	zinc	,,	silver	12	(=5+1+3+2+1)
,,	zinc	,,	iron	9	(=5+1+3)
,,	lead	,,	copper	6	(=1+3+2)

The difference value between zinc and silver is equal to the sum of the difference values between zinc and lead, lead and tin, tin and iron, iron and copper, copper and silver. The correctness of this law has been confirmed by Kohl-

rausch with the help of his condenser. Kohlrausch took the difference of potential produced by contact between copper and zinc to be 100, and obtained for the rest of the metals the following values:

	A determined experimentally.	*B theoretically.*
Between zinc and copper	100	
,, zinc ,, gold	112·7	
,, zinc ,, silver	105·6	
,, zinc ,, iron	74·7	
,, iron ,, copper	31·9	25·3
,, iron ,, platinum	32·3	32·3
,, iron ,, gold	39·7	38
,, iron ,, silver	29·8	30·9

The values given as theoretical are based on the contact law. This law has been further investigated experimentally by others, as, for instance, Hankel, and proved to be correct; it has, however, been found that the nature of the surface of the metals in contact influences the results obtained. This may be the reason why the lists of some experimenters do not agree with those of others. Volta"s law may be stated as follows: *The difference of potential between any two metals is equal to the sum of the differences of potentials of all the intermediate members of the series;* consequently, it is immaterial for the total effect whether the first and the last are brought into contact directly, or whether the contact is brought about by means of all or any of the intermediate metals. We can easily see this from the values which Volta obtained. If, for instance, we bring silver and zinc to touch each other, we obtain the difference value 12; if now we place upon the zinc plate a lead plate, then tin, iron, copper, and finally the silver plate, we obtain for difference values 5, 1, 3, 2, the sum of which is 12. Volta's law further proves that when any number of metals are brought into contact with each other, but so that the chain closes with the metal with which it was begun, the total difference must be nought. We obtain for zinc, lead, tin, iron, and finally for zinc the following values:

For zinc and lead + 5
,, lead and tin + 1
,, tin and iron + 3
,, iron and zinc − 9.

The sum for the values of the three first contacts is equal to + 9, the last value is − 9.* Hence the whole sum is nought.

Experiments have further proved that the time of contact does not influence the difference value, which is easily explained, since by the contact only a statical condition is effected. The action is similar to the induction between conductors, which takes place instantaneously, and does not change, no matter how long the influenced and the influencing body are left together. The

* The signs + or − depend, of course, upon the order of the metals in contact.

difference values are not changed when the points of contact between the two plates are changed; therefore it is not at all necessary that the plates should actually touch each other; it is sufficient to connect them with each other by means of a conducting wire.

Numerous experiments have shown that all metals become negatively electrified when in contact with alkaline liquids; but in contact with acids different metals behave differently. Gold, platinum, and silver become positively electrified when immersed in either H_2SO_4, HNO_3, or HCl. Zinc, however, when immersed in these acids, becomes negatively electrified. As we cannot range metals and liquids in one list, owing to their different behaviour with different acids, we arrange them therefore in two classes, viz., first-class conductors and second-class conductors. Conductors of the first class are all those bodies which can be classified among the lists already given. Conductors of the second class are all those bodies that, although capable of conducting electricity, cannot be ranged in the lists given. The following table shows the values Péclet obtained when bringing metals into contact with liquids:

	H_2SO_4 diluted.	HNO_3 diluted.	Potash.	Potassium Sulphate.
Zinc	− 27	− 26	− 30	− 30
Lead	− 14	− 13	− 24	− 17
Iron	− 13	− 8	− 19	− 17
Copper	− 2	not	− 11	− 22
Platinum... ..	+ 6	+ 4	− 5	− 17

This table shows that the metals highest in the list become electrified strongest, and negatively. The following values are obtained when metals were brought into contact with water, by Gerland, taking for copper with zinc, 100:

Zinc	61·6
Copper	33·0
Gold	33·7
Silver	17·0
Platinum...	44·7

The fact that liquids cannot be arranged in the list has important consequences, which enables us to obtain free electricity in a closer circuit, which, as we know, is impossible to obtain from conductors belonging to the first class; as the series commencing and ending with the same metal has a difference value of 0. To see this more clearly, we have grouped the conductors given in the list in a circle, represented in Fig. 76. We notice that every member may be considered as beginning and ending the series, and the circuit therefore is closed. If, however, such a closed circuit consists of conductors belonging to the first and second classes, as shown in Fig. 77, the result will be a different one.

As already stated, the difference values are as follows :

Copper and water	− 33·0	
Water and zinc		+ 61·6
Zinc and silver		+ 105·6
Silver and iron	− 29 8	
Iron and gold		+ 39·7
Gold and copper	− 12·7	
	− 75·5	+ 206·9

which gives for the total difference + 131·4 ; showing that for a perfectly closed circle consisting of conductors belonging to the first and second class, the total

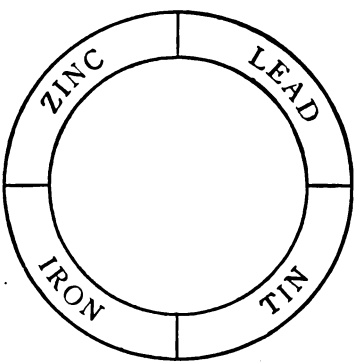


Fig. 76.—Closed Circuit of Metals.

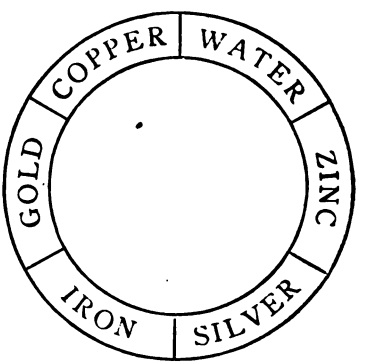


Fig. 77.—Closed Circuit including a Liquid.

difference value will not be o. From this behaviour a further deduction can be drawn which is important as regards the proper understanding of the behaviour of galvanic elements. In our illustration (Fig. 77) only the two metals copper and zinc are in connection with water ; the other metals are in contact with each other ; but for this series of metals the law enunciated already holds good—that is, it is immaterial whether we take zinc, silver, iron, gold, and copper, and let them touch each other, or whether we make contact with zinc and copper only. According to this we have then in our circle the following values ·

Copper and water	− 33·0	
Water and zinc		+ 61·6
Zinc and copper	−	+ 100
	− 33·0	+ 161·6

which gives us a total of 128·6. If we compare this with the result obtained in the difficult task of determining the number given in the table, namely, 131·4, the two agree so nearly that we may account for the difference by allowing for inaccuracies in observations, etc. These and similar experiments enable us, then, to lay down the law, that when two different metals are immersed in a

liquid and connected with a series of different metals forming a closed circuit, the difference value of this circuit only depends upon the two metals immersed, and upon the fluid. The same difference value is then obtained, no matter what or how many metals we employ to form the outer circuit. The difference value only depends upon the nature of the immersed metals and upon the liquid.

We can now explain why the results obtained immediately after dipping the metals into liquid do not agree with results taken after the metals have been for some time in the liquid. In the latter case the liquids have already chemically influenced the metal. For metals when *first* immersed in fluids, Wüllner constructed the following table:

ORDER OF METALS IN DIFFERENT LIQUIDS.

WATER. +	DILUTED H_2SO_4. +	DILUTED HNO_3. +	CONCENTRATED HNO_3. +	POTASSIUM CYANIDE. +
Zinc.	Zinc.	Zinc.	Cadmium.	Amalgamated zinc
Lead.	Cadmium.	Cadmium.	Zinc.	Zinc.
Tin.	Iron.	Lead.	Lead.	Copper.
Iron.	Tin.	Tin.	Tin.	Cadmium.
Antimony.	Lead.	Iron.	Iron.	Tin.
Bismuth.	Aluminium.	Nickel.	Bismuth.	Silver.
Copper.	Nickel.	Bismuth.	Copper.	Nickel.
Silver.	Antimony.	Antimony.	Antimony.	Antimony.
Gold.	Bismuth.	Copper.	Silver.	Lead.
Olefiant gas (etheric).	Copper.	Silver.	Nickel.	Mercury.
Ethereal oils.	Silver.			Palladium.
	Platinum.			Bismuth.
				Iron.
				Platinum.
				Cast-iron.
				Carbon.

Nobili was the first who showed that when two liquids are in contact they produce a difference of potential *or* E. M. F.; but Fechner, Wild, and others investigated the subject more thoroughly. Wild made use of a little wooden box for his experiments, shown in Fig. 78; two glass tubes, B D, were attached to the bottom of the box; the glass tubes terminated in copper caps, which were in connection with the galvanometer. Before each experiment the copper bottoms of the glass tubes had to be carefully examined, to see whether they would not generate a current when in contact with any one fluid, that is, whether they were perfectly homogeneous; then liquid f_1 was introduced; after that, liquid f_2. Care was taken not to mix f_1

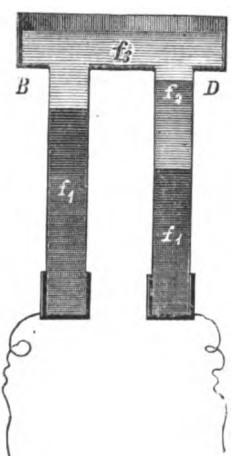


Fig. 78.– Production of an E. M. F. by Liquids in Contact.

with f_2. Finally, liquid f_3 was introduced under the same precautions. With this arrangement a marked difference of potential was easily shown by a galvanometer placed in the circuit between the two copper caps or terminals.

Grove's Gas Battery.—Electrical differences are further observed when metals are brought into contact with gases; this was properly investigated first by Grove (1839). The apparatus he used for the purpose is shown in Fig. 79. The glass tubes O H are open at the lower ends, and have platinum wires fused into the upper ends. These platinum wires terminate on the outside with platinum cups, and on the inside with platinum strips, coated with spongy platinum. The bottle and its tubes are filled with water slightly acidulated with sulphuric acid. Mercury is placed in the little platinum cups, and the wires from a galvanometer are dipped into it. Oxygen and hydrogen are now forced into the tubes so as to depress the level of the water until the tubes are full of gas. The needle of the galvanometer shows at once a deflection, indicating that a current flows from the hydrogen tube to the oxygen tube; at the same time a falling of the water level in the two tubes is observed: the water in tube H rises twice as quickly as that in the tube O.

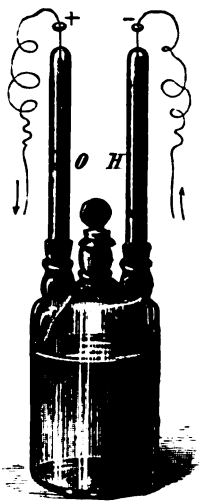


Fig. 79 —Grove's Gas Battery.

If we first arrange a battery of cells in the circuit in such a way that we can exclude the battery when we choose, but leave the circuit completed with the galvanometer included, then, starting with both tubes full of water, on making contact, the current will decompose the water, and at the same time deflect the needle. When the tubes become full of the gases we cut out the battery, and the needle of the galvanometer is at once deflected in the other direction, showing that the current produced by the gases is opposite to that which liberates them. The two tubes being perfectly similar in all respects to each other, the gases only can be the cause of the current. This latter form of the experiment is important, as being the first recorded example of the storing-up for subsequent use, in the production of a reversed current, of electrical energy. This principle has recently become of considerable practical importance, and has been more successfully applied in several forms, which will be described in the second portion of this work.

The rise of the liquid in the two tubes is due to the union of the gases, which is brought about as follows:—The effect of the current is to decompose water, and to cause the O to separate out in the tube filled with H, the hydrogen in the tube filled with O. It is a characteristic quality of spongy platinum that it is capable of absorbing gases, and bringing them so near each

other at its surface as to cause chemical combination. In consequence of this effect of spongy platinum, H and O in the same tube unite and form water, two volumes of H combining with one volume of O. The liquid in the tube filled with H will therefore rise twice as quickly as in the tube filled with O. Now we may account for the phenomenon on the contact theory by supposing the difference of potential to be produced at the contact of H with platinum. That is to say, by regarding H and Pt. as dissimilar metals. H by being in contact with the platinum plate becomes positively electrified, whilst the plate receives negative electricity. How is the platinumplate affected by the O? To answer this question we leave out the O. One of the glass tubes is filled with H whilst the other contains water. If now the wires be attached to the galvanic battery, the needle shows almost the same deflection as in the first experiment; by-and-by, however, the deflection diminishes. The current, then, is due to the H alone in contact with the platinum plate, for if on contact O and Pt. produced any E. M. F., the first deflection of the needle, when the O was left out, ought to have been less. The diminution of the needle's deflections, after a little time, is due again to the decomposition of the water by the current; more O is given off in the hydrogen tube, H is given off in the tube filled with water. Consequently the platinum plate in the water tube will be surrounded more and more by H, whilst the other tube has its quantity of H diminished. Hence both platinum plates are after some time in contact with the same gas, and the electrical difference must come to an end. The reversal of this experiment also shows that platinum in contact with O has almost no electrical effect whatever. Oxygen is brought into one of the tubes, whilst the other is left filled with water. The deflection of the needle will hardly be perceptible now, the very small deflection, however, indicating that oxygen in contact with platinum electrifies the latter negatively, but only very slightly.

A great number of gases and vapours were examined by Grove, and he found that gases can be arranged with the metals in a series, graduated according to the difference of potential or E. M. F. they will produce. When, as with metals, we commence with electropositive substances first, we get the following table:

1 Metals which decompose water.	7 Ether.	13 Carbonic acid.
2 Hydrogen.	8 Olefiant gas.	14 Nitric acid.
3 Carbonic oxide.	9 Ethereal oils.	15 Oxygen.
4 Phosphorus.	10 Camphor.	16 Peroxides.
5 Sulphur.	11 Metals which do not decompose O and H.	17 Iodine.
6 Alcohol.	12 Nitrogen.	18 Bromine.
		19 Chlorine.

If we take one of the metals that does not decompose water, and bring it into contact with a gas lower down in the list, the metal becomes positively electrified, the electrification being the stronger the farther gas and metal stand from each other in the series.

GALVANIC BATTERIES.

By a galvanic battery is understood the connection of several galvanic elements in the manner shown in Fig. 80. Here the zinc of the first and the copper of the last only are free. The zinc plate, as has been mentioned already, becomes electrified at its free end when immersed in diluted H_2SO_4, and forces the positive electricity into the free copper end; this happens throughout in every element; the elements being connected with each other, the process is as follows. The positive electricity from the first zinc passes through the first liquid to the copper of the first element and the zinc plate of the second element, which is in electrical connection with the copper of the first. The zinc plate of the second element has now its own amount of + electricity, and the + elec-

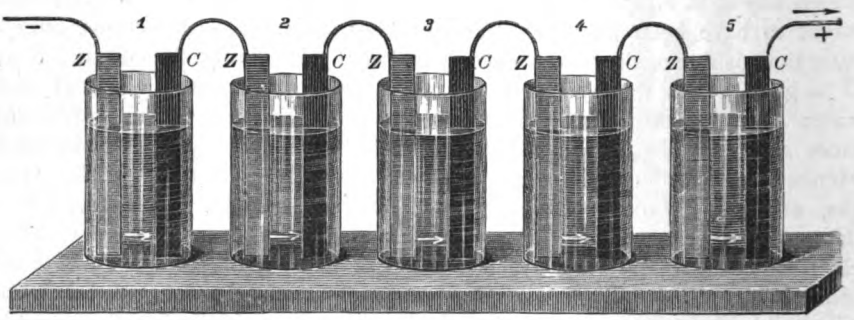


Fig. 80.—A Galvanic Battery.

tricity from element 1. Element 2 now sends its whole amount of + electricity to element 3, and so on. The amount of positive electricity sent forward increases with the number of elements. In the battery (Fig. 80) the amount of electricity sent forward will be five times as great as it would be with only one element. Negative electricity takes the opposite direction; each immersed copper forces the negative electricity into the neighbouring zinc, and the total amount of negative electricity appears at the free zinc end of the battery. If we connect the free zinc end by means of a wire with the free copper end, the circuit is closed, and a current flows through the wire: negative electricity from zinc to copper, and positive electricity from copper to zinc; whilst in the liquid the current has the opposite direction.

There is another way of looking at this action of a number of elements connected in series. Each produces its own difference of potential. But the potential of the zinc and copper plates that are connected by a clamp having no resistance is the same. Hence the total difference of potential resembles the total difference of level in a flight of stairs. Each step adds its own height

only, but each starts from the level of the last. If a be the difference of potential or E. M. F. of each element, then the first gives a difference a, the first two $a+a$, the first three $a+a+a$, and so on.

In the first battery or pile constructed by Volta, pieces of zinc and copper were soldered together. Volta gave his later batteries the form of a pile

Fig. 81.—Volta's Pile.

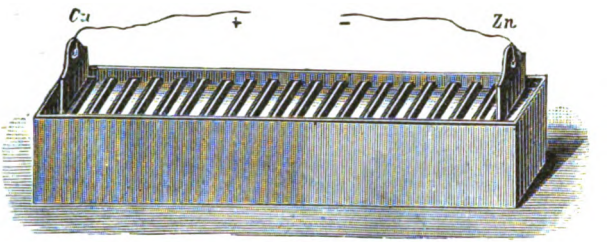


Fig. 82.—Cruikshank's Battery.

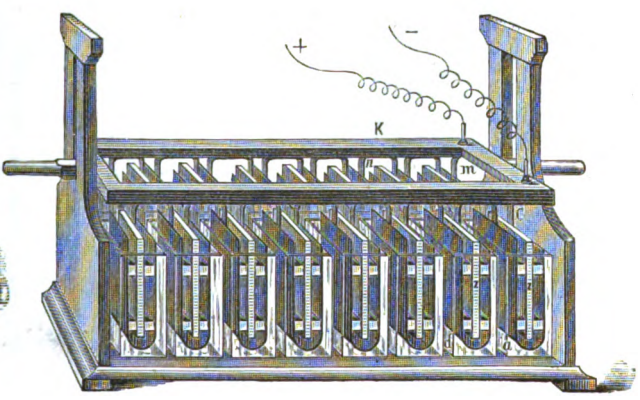


Fig. 83.—Wollaston's Battery.

(shown in Fig. 81), which consisted of pieces of flannel or cloth soaked in dilute sulphuric acid and laid between the copper and zinc plates. The voltaic battery soon underwent many alterations; Cruikshank, for instance, gave it the form shown in Fig. 82, and Wollaston the form shown in Fig. 83. Here we have the important improvement of all couples being contained in separate cells $a\,d$ of glass or porcelain, to hold the exciting fluid. In each cell the zinc plates $z\,z$ are kept centrally adjusted by wooden slips between the halves of a doubled copper plate bent round under them; and the whole set of plates, connected by strips of copper m, being attached to the wooden frame K, can at pleasure be lifted out of the fluid, and the action thus stopped without emptying the cells. All these points, modified according to the construction, are retained in many of the batteries

used at the present day. To secure a large surface to both plates, Hare placed large copper and zinc sheets together, separating them by means of pieces of wood, and rolling them into a cylindrical shape. His instrument is known under the name of Hare's calorimeter, and is represented in Fig. 84.

Dry Piles.—Dry piles—that is, batteries where no fluids were used—were first constructed by Behrens (1806), De Luc, and Zamboni. Behrens

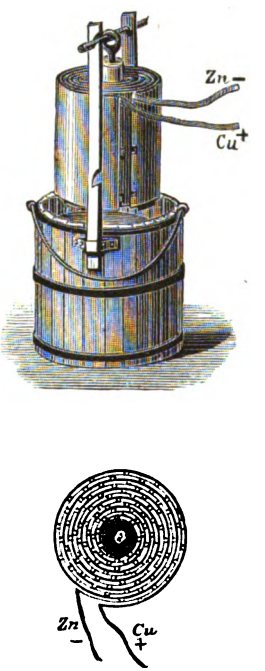


Fig. 84.—Hare's Calorimeter.

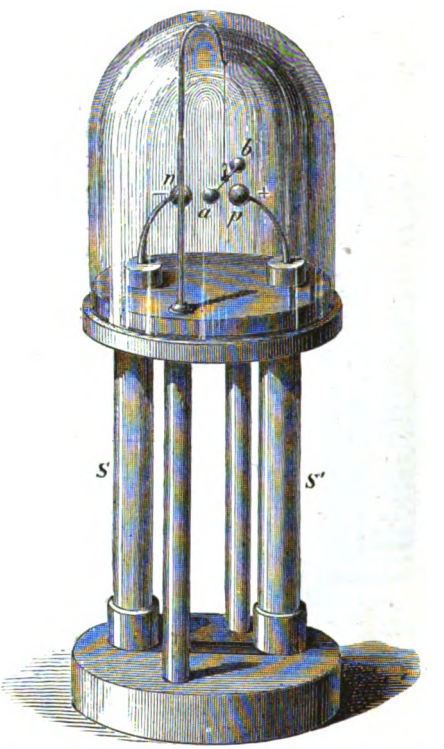


Fig. 85.—Behrens' Instrument for producing Perpetual Motion.

made use of dry piles for the construction of his *perpetuum mobile*, shown in Fig. 85. s s′ are dry piles, one with the negative pole uppermost, the other with the positive pole uppermost. These poles terminate in the balls *n* and *p*, between which there hangs a light pendulum *a b*, which is attracted by one electrified pole, and then repelled. The next pole will now attract the pendulum and then repel it, and so on. It need not be mentioned that this "perpetual motion" in no way interferes with the laws of forces and energy. The pendulum, once in motion, may continue in motion for years, but electricity is the motive force, and it will stop when the power of the instrument to produce electricity

is exhausted. Rousseau made a dry pile in the construction of his diagometer, an instrument which makes use of the different conducting powers of substances for the determination of their chemical combination (Fig. 86). The lower pole *m'* is connected with the earth, while from the upper pole *m* a wire passes to the needle M. This needle is slightly magnetised, and has a little plate at one of its ends. At the same height as this movable plate is another fixed insulated plate L. When the instrument is brought with its axis into the magnetic meridian, the discs will touch each other. If now the needle is connected with the upper pole of the pile, both plates become similarly electrified, and repel each other. The needle will come to rest as soon as equilibrium is restored between

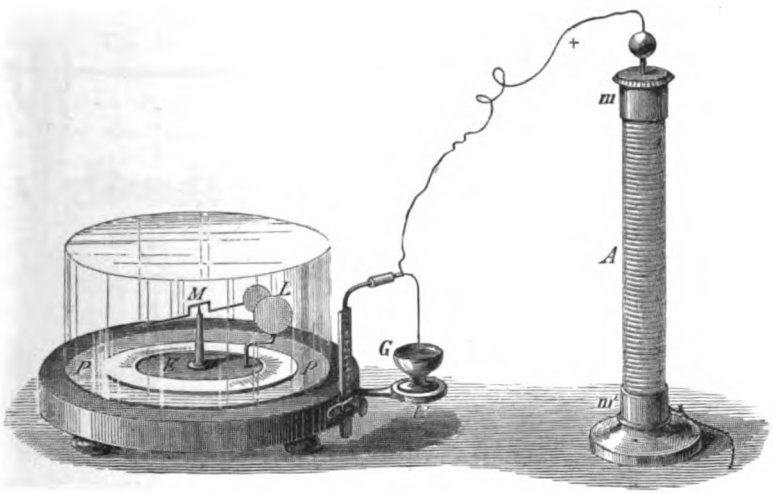


Fig. 86.—Rousseau's Diagometer.

the force of repulsion and the earth's magnetism. Equilibrium is quickly restored when the pole and the needle are connected by a conducting substance, but it takes some time when a bad conducting substance makes the connection. The time the needle requires to gain its fixed position measures the chemical purity of the substance under examination. To enable the experimenter to insert substances more conveniently, the wire of the pile is made to dip into a little basin G, which is in conducting connection with L'. With the help of this instrument Rousseau especially examined oils and fats. Coffee when powdered does not conduct electricity; if, however, adulterated with chicory, it will; the same with chocolate—if pure it will not conduct electricity.

Zamboni's pile, as used at present for telescopes, is generally prepared in the following manner: ordinary silver paper is coated on its back with a thin layer of manganese dioxide, mixed with some such substance as gum to make it stick. The sheets prepared in this manner are cut into discs, and are placed between two metal plates fastened with silk threads. To

prevent the evaporation of the moisture, the whole pile is placed under a glass cylinder.

Polarisation of Plates in a Single-Fluid Battery.—The batteries we have described up to the present—that is to say, batteries consisting of two different metals and a liquid—soon show a considerable falling off in their efficiency. The cause of this is the decomposition of the liquid by the electrical current. Water is decomposed into hydrogen and oxygen. H is given off at the positive pole (the copper plate), and O at the negative pole (the zinc plate). The zinc becomes oxidised and forms protoxide of zinc, which is soluble in H_2SO_4, and forms zinc sulphate. The zinc plate then is constantly kept clean, but not so the copper plate. The hydrogen by degrees covers the

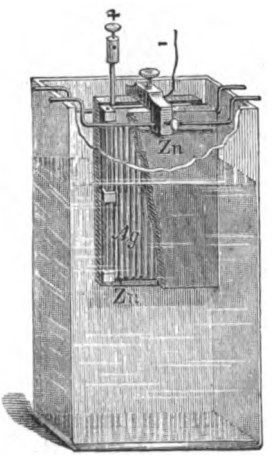


Fig. 87.—Smee's Element.

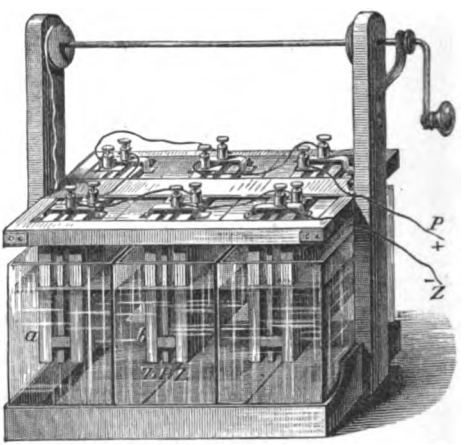


Fig. 88.—Smee's Battery.

whole surface of the copper plate with a layer of hydrogen gas, and this becomes positively electrified, and causes a positive current in the liquid—that is, a current opposite to the one generated by the two metals and the liquid. This opposing current, then, is the cause of the diminution of the strength in the battery. To prevent this, both chemical and mechanical means have been employed.

Smee's Battery.—Smee (1840) succeeded in overcoming the injurious effects of this polarisation of the electrodes by mechanical means. The element constructed by him is shown in Fig. 87. In a rectangular glass vessel two zinc plates *zn* are placed, held together by a screw. Between the two zinc plates, well insulated, is a platinum plate (sometimes silver covered with platinum). The vessel itself is filled with diluted H_2SO_4; it is purposely taken larger than the plates require, in order that the zinc sulphate which is forming may not come into contact with the plates, and may remain at the bottom of the vessel. Fig. 88 represents several elements together.

Two-Fluid Batteries.—In two-fluid batteries, in addition to the ordinary acidulated water that acts on the zinc, substances which easily part with their O are put into the battery. This O combines with the liberated H to form water. To prevent the mixing of the two liquids, the one containing oxygen is placed in porous vessels, which allow gases, but not liquids, to pass. The use of the above remedy led to the construction of so-called constant batteries, of which the first was devised by Daniell, in 1837.

Daniell's Element.—This in its original form is shown in Fig. 89, where *b* is a copper jar forming the + plate, and *c* a porous cell of some kind containing a zinc cylinder in the middle, forming the − plate. The liquid *o o* in the closed porous cell is dilute sulphuric acid, supplied through the small funnel. The height of this liquid could be seen by means of the tube *g*, through which, also the superfluous acid could be drawn off.

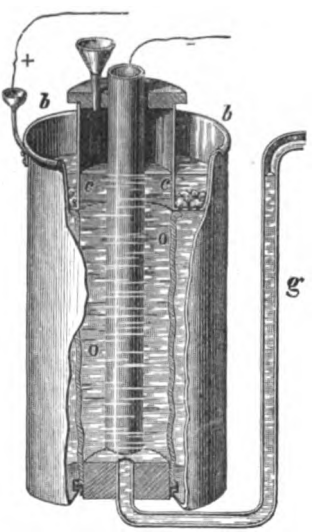


Fig. 89.—Daniell's Element.

It will be seen, therefore, that the Daniell's element consists of an inner and outer cell, separated by a porous partition; copper and zinc being the metals. The copper does not waste, and may therefore be used for the outer cell, although this is not an essential feature. The porous cell may be made of unglazed porous porcelain, or of lighter material, such as parchment, or even of brown paper. When the amalgamated zinc is placed in the inner cell, and the copper plate forms the outer receptacle, the liquid in the inner cell is dilute sulphuric acid, and that in the outer cell is a saturated solution of copper sulphate or blue vitriol. It is desirable that this solution should be *saturated*, that is, should contain as much copper sulphate as it will dissolve, and, as the action decomposes this compound, spare crystals of the substance must be placed in a cage at the top of the liquid. These will gradually dissolve as the other is used up. The action when the circuit is closed is as follows: Zinc dissolves in the dilute H_2SO_4 forming $Zn\,SO_4$, and liberating H. The freed atoms of H, however, do not collect on the copper, but are handed on to the porous cell, through the pores of which they pass to replace copper in the copper sulphate. The result is that pure copper instead of H is deposited on the outer plate, which therefore thickens. Hence

$$\text{in the inner cell } Zn + H_2SO_4 = Zn\,SO_4 + H_2;$$
$$\text{in the outer cell } H_2 + Cu\,SO_4 = H_2SO_4 + Cu.$$

Fig. 90 represents a modification of the element, having the copper in the inner cell and the zinc in the outer cell. *zn* is the zinc cylinder placed in a glass

vessel, *t* is the porous pot into which the copper rod *c* dips. The copper carries a little sieve D, to hold crystals of sulphate of copper. Each copper rod is connected with the next zinc cylinder by means of the wire *a*.

Grove's Element.—A more efficient, though not more constant element than Daniell's, was first used in 1839 by Sir William Grove, Master of the Mint. The E. M. F. of a Grove's cell is 1·8 that of a Daniell's. It also consists of two cells, one within the other, and two acids besides the two metal plates. The outer vessel, in which the zinc plate is placed, is usually made of glass, porcelain, or a non-conducting composition. Inside this zinc plate comes the porous pot, which has the platinum plate, bent in the shape of an **S**. The glass vessel is filled with diluted H_2SO_4, and the porous pot with concentrated HNO_3. When the battery is in action, water is decomposed and the hydrogen reaches the nitric acid (HNO_3) through the porous pot, and takes up some of its oxygen to form water. The nitric acid is thus reduced.

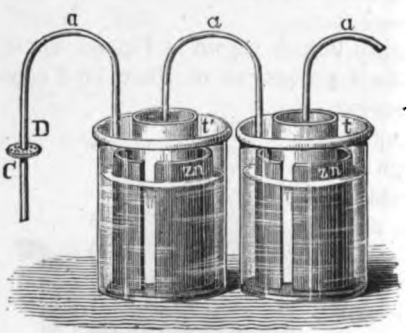


Fig. 90.—Daniell's Elements.

The chemical change may be expressed by one or other of the following equations, starting with two molecules of nitric acid:

$$2HNO_3 + 3H_2 = 4H_2O + 2NO; \text{ or } 2HNO_3 + 2H_2 = 3H_2O + 2HNO_2.$$

In the second case the $2HNO_2$ breaks up into

$$H_2O + NO + NO_2; \textit{ i.e.}, \text{ water + nitric oxide + nitric peroxide.}$$

The nitric oxide forms red fumes when it comes into contact with common air.

Zinc sulphate is again formed in the outer acid, but the water and nitric oxides remain in the porous vessel. The action of the cell remains constant only so long as there is undecomposed nitric acid in contact with the platinum plate. The disadvantages of this cell (Fig. 91) are the nitrous fumes and the high price of platinum.

Bunsen's Element.—Fig. 92 represents an older form of Bunsen's cell, in which carbon is substituted for Grove's platinum plate. In this

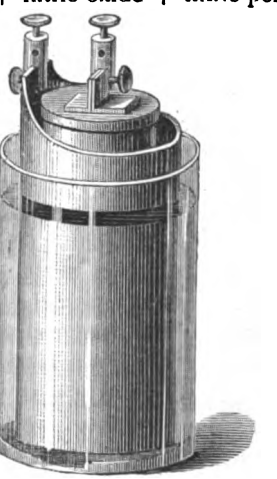


Fig. 91.
A Grove's Element.

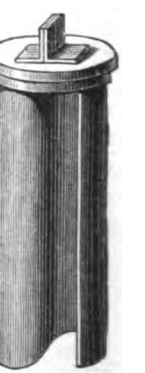


Fig. 92.
The Platinum.

original cell, the carbon was cut so as to fit in the outer cell; but the difficulty of cutting the carbon has led to the transposition of carbon and zinc, the latter being placed in a cylindrical form in the outer cell, and the former being simply a rod, either round or square in section, placed in the middle. The preparation of the carbon, and the modifications the cell has undergone, will be treated in the second part of this work, to which we must also refer for other forms of battery.

Thermo-Electricity.—The first who pointed out that a current was generated when the joints of different metals were kept at different temperatures was Seebeck, and the apparatus he used for the purpose is shown in Fig. 94. A piece of copper K, bent in the shape seen in the figure, was placed on a block of bismuth *a b*, having a movable magnetic needle *n s;* as soon as the temperature was altered by either heating or cooling the junctions of the two metals, the deflection of the needle indicated a current which continued to flow as long as the difference of temperature was maintained at the junctions. The needle indicates the direction in which the current flows. If, for instance, the north end *b* be heated, the needle moves east, showing that at the heated junction the current flows from the bismuth to the copper, at the cold junction from the copper to bismuth. Not only will bismuth and copper generate currents, but almost any two metals will do the same. Seebeck arranged a table of metals in thermo-electrical order, as follows:

Fig. 93.—The first Bunsen's Patent.

+ Antimony	Gold	Platinum
Arsenic	Tin	Cobalt
Iron	Lead	Nickel
Zinc	Copper	Bismuth
Silver		

This order only holds good for temperatures within certain limits, and the structure of the metals, etc., ought to be taken into account. Bismuth and antimony, being farthest from each other in the list, are best for the construction of thermo-electric elements. The power of any element as a rule increases with the increase of difference of temperature between the two junctions up to certain limits, and if the difference of temperature between be made still greater, the current may cease altogether, or flow in an opposite direction to that in which it flowed when the difference of temperature was not so great. The limit is

different for different couples. In the case of a copper-iron pair the neutral temperature is 280°, and beyond this difference there is an inversion of the current.

Thermo-electric elements generate constant currents as long as the temperature at the junctions is kept constant. The easiest way to secure this is to place one of the junctions in boiling water, the other in melting ice. The former will have a constant temperature of 100° C., the latter a constant temperature of 0°. The electromotive force of the thermo-electric elements compared with that of the galvanic elements is very small: for instance, the electro-motive force of pure silver and copper is about $\frac{2}{1000}$ of a Daniell's element. If we take this electro-motive force as unity, we obtain the following values:

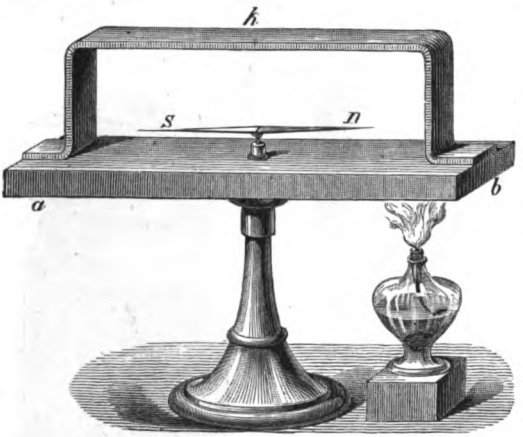


Fig. 94.—Seebeck's Thermo-Electric Apparatus.

Silver and Bismuth	32·9
,, ,, Germansilver	5·2
,, ,, Mercury	2·5
,, ,, Lead	1·0
,, ,, Antimony	9·87
,, ,, Tellurium	179
,, ,, Selenium	290

Alloys may also be used for thermo-electric purposes, but they do not follow exactly the order which might be expected from their relation to the metals from which they are derived. Seebeck obtained the following order for the principal alloys:

−	+
Bismuth	Zinc
Lead	3 bismuth, 1 lead
Tin	1 antimony, 1 copper
1 bismuth, 3 tin	1 antimony, 3 copper
1 bismuth, 3 lead	1 antimony, 3 lead, 3 antimony, 1 lead
Platinum, No. 2	1 antimony, 3 tin, 3 antimony, 1 tin
1 bismuth, 1 lead	Steel (cast)
Gold, No. 1	Steel (rod)
Silver	3 bismuth, 1 tin
1 bismuth, 1 tin	1 bismuth, 3 antimony
	Antimony
	1 antimony, 1 tin
	3 antimony, 1 zinc.

The thermo-electric elements can be united to form batteries, as shown in Fig. 95, but care must be taken that the even numbers 2, 4, come on one side,

the odd numbers, 1, 3, 5, on the other side, so as to be convenient for heating the one and cooling the other. Such a battery is usually called a thermopile.

The circumstance that the electromotive force of a thermopile is proportional to moderate differences of temperature, makes it a valuable and delicate instrument for measuring temperature. For this purpose the wires of the pile are connected with a very sensitive galvanometer. The slightest difference of temperature generates a current; and the strength of this current, which is proportional to the difference of temperature for a considerable range, is indicated by the deflection of the needle. According to Melloni, $\frac{1}{5000}$ of a degree can be measured with this instrument, a minute difference which, of course, cannot be obtained with any other thermometer. Thermopiles are constructed of different shapes; but the form generally used for experiments on heat is that of a cube (Fig. 96). All the even junctions lie on one side and the uneven on the other side. The complete apparatus is

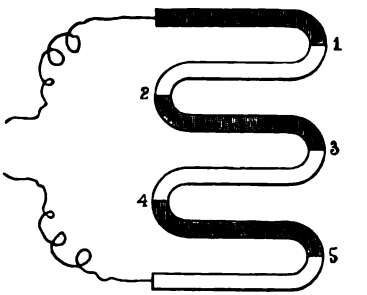


Fig. 95.—Thermo-Electric Battery.

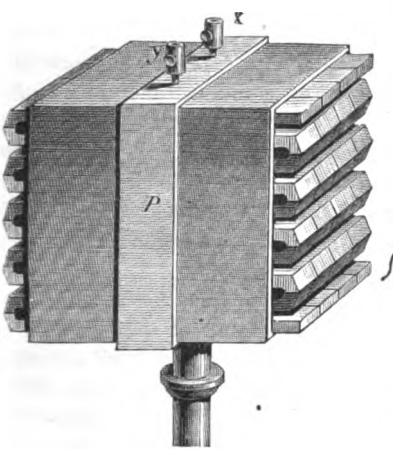


Fig. 96.—The Thermopile.

Fig. 97.—Melloni's Thermopile.

shown in Fig. 97. For certain purposes, *e.g.*, for ascertaining the comparative temperature at any given lines in the spectrum, thermopiles are used having the even and odd junctions arranged in straight lines. In some cases the thermo-electrical needle is of service. This consists of one element, the junction of which is pointed, and the free ends connected with a galvanometer. With it the condition as regards heat of animal and vegetable textures is investigated.

LAWS AND MEASUREMENT OF THE GALVANIC CURRENT.

Ohm's Law: Illustrations and Explanations.—We know that by putting two different metals into a liquid we create an electromotive force, which causes a motion of the electricities, or a galvanic current. This galvanic current lasts as long as the chemical action lasts, and flows from points of higher to points of lower potential. Let us consider again the simplest form of galvanic element, namely, that consisting of a copper plate and a zinc plate in dilute sulphuric acid, the free ends of the plates being joined with a wire. Every similar arrangement is called a closed element. In our combination positive electricity moves from the free copper end to the free zinc end, and negative electricity in the opposite direction. We further know that motion of the electricities is not restricted to the connecting wire, but extends to the plates dipped in the liquid, and to the liquid itself. In the liquid positive electricity flows from the zinc to the copper, and negative electricity from the copper to the zinc. In the element, then, there circulate two distinct currents, opposite to each other. But as all the effects produced by a flow of positive electricity in one direction are identical with those produced by a flow of negative electricity in the opposite direction, we need only consider the current of one kind in one direction. Consequently, when we speak of the *direction of the current*, we mean the direction of flow of positive electricity, or the direction of fall of potential.

To explain the laws of the current we will return to the analogy of a flow of water. The reservoirs A and B in Fig. 98 stand at different heights. As long as this difference of level is maintained, water from B will flow through the pipe R to A. If by means of a pump P the level in B is kept constant, a constant flow through R will also be maintained. Here, by means of the work expended on the pump, the level in the reservoir is kept constant, and in the corresponding case of the electrical current, by the conversion of chemical energy a constant difference of potential is maintained.

Through every cross section of the water circuit a certain quantity of water flows per second, and this quantity may be taken as the measure of the strength of current. Similarly, through every cross section of a conductor flows a certain quantity of electricity in a given time. That quantity of electricity which flows in one second through any one cross section of a conductor is called the strength or intensity of the current. If 10 litres of water flow in every second into a vessel of any shape, and 10 litres flow out again per second, it is evident that through every cross section of the vessel, or of the pipe leading to it, 10 litres of water pass every second. The quantity of water that flows through the vessel is independent of the cross section of the vessel. The same condition holds good for the galvanic current; if in a closed circuit a constant current circulates, the same amount of electricity will pass every cross section per second. Hence the following law: *The strength of a constant current in any circuit is equal in all parts of the circuit.*

Again, we shall increase the quantity of water flowing through the circuit in a given time by increasing the pressure producing the motion; that is to say, by increasing the difference of level of the reservoirs (Fig. 98). Now, the pressure per square centimetre and the difference of level are both given by the same number. Similarly, in electricity the difference of potential produced by the contact of metals and liquids, and the E. M. F. producing the current, are measured for most purposes by the same number; therefore we may treat the terms as synonymous. Whenever we are dealing with the measures of quantities amongst which there are a difference of potential and an electromotive force, we may, as a rule, replace one of these by the other, for their measures are identical.

As the strength of the current in the water system is proportional to the difference of level of the cisterns, or to the pressure exerted, so also in the electric circuit the strength of the current is proportional to the difference of potential produced by the battery, or to the electromotive force that results from it.

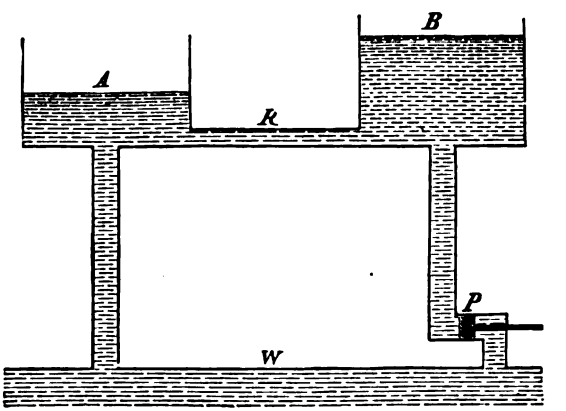


Fig. 98.—A Circuit of Water analogous to the Galvanic Circuit.

The quantity of water flowing through a pipe during a given time will be increased when the pressure is increased; the water then flows quicker, and therefore a greater quantity must pass every cross section in a given time.

The pressure of the reservoir B (Fig. 98) can be increased by placing another reservoir over it, covering B, and connecting it with the higher reservoir; similarly the E. M. F. in a circuit may be increased by placing two elements in series. The difference of potentials in the cell is the cause of the motion of the current, and determines the pressure or E. M. F., and therefore also the quantity of electricity flowing for any given time through any cross section of a circuit. If, therefore, we connect several cells we increase the electromotive force and increase the current; in other words, the intensity of the current increases with the E. M. F.

The strength or intensity of the current depends, however, upon something else. In the water circuit it depends on the connecting pipes; the thicker the pipes, the greater the flow, and the smaller the pipes the less the flow with the same pressure. Similarly the strength of the electric current depends on the connecting wires. It has been mentioned that different substances

conduct electricity differently; and every body opposes a certain resistance to the passage of electricity. The quantity of electricity passing per second from one point to another depends on the resistance of the wire or conductor joining the two points, when a constant difference of potentials is maintained between them, and the amount of electricity flowing through a cross section must become less when the resistance increases. If we take these propositions together, we obtain the law named, after its discoverer, Ohm's law. The current is directly proportional to the E. M. F. and inversely proportional to the resistance. The current is increased two-, three-, four-fold when the E. M. F. is increased two-, three-, four- fold; the current is diminished two-, three-, four-fold when the resistance is increased two-, three-, four-fold.

$$\text{Hence, current} = \frac{\text{E. M. F.}}{\text{resistance}}$$

Resistance of Wires.—We have, then, three factors which have to be considered in every galvanic current. Let us now see upon what circumstances these factors depend. Let us take a Daniell's cell, having a certain length of copper wire and a galvanometer in circuit. The current will cause a deflection of the needle through a certain angle. If now we double the length of copper wire, we shall find that the deflection is at once diminished. As we lengthen our wire we obtain smaller and smaller deflections. If we take wires of different cross sections, we again obtain different deflections; the deflection becomes larger the larger the cross section of the wire inserted; in other words, the thicker the wire the less the resistance. This holds good, not only for copper wire, but for every substance inserted in a circuit. Again, the material as well as the form has to be considered; if, for example, we take one metre of iron wire and one metre of silver wire of the same cross section, and try the same experiment, we find different deflections for each. The resistance of a unit cube of the material of the conductor is called the specific resistance. To give the specific resistance of different substances a unit has to be adopted; that is, the resistance of some substance or other must be taken as 1. If, for instance, we take the resistance of a unit cube of copper to be 1, we shall find the resistance of platinum 3·57, German silver 5·88, and so on.

The laws of the resistance of conductors may therefore be collected as follows:

1. *The resistance of a conducting wire is proportional to its length.*

2. *The resistance of a conducting wire is inversely proportional to the area of its cross section.*

3. *The resistance of a conducting wire of given length and thickness depends upon the specific resistance of the material of which it is made.*

$$\text{Thus the resistance} = \frac{\text{specific resistance} \times \text{length}}{\text{area of cross section}}.$$

Resistance in the Internal Circuit.—The laws with which we have familiarised ourselves enable us to connect single elements with each other, to

form batteries, in the most advantageous manner. Elements may be connected with each other in several ways to form a battery; the usual way, as shown in Fig. 99, is to connect the electro-positive metal with the electro-negative metal of the next element, and so on. This arrangement of elements to form a battery we have already referred to as connection in series. The electrical current flows here in the fluid of the first element, from zinc to copper, through the connecting wire to the zinc of the second element, unites with the current generated there, and flows along with it to the third element, and so on, until the last element is reached, when it leaves the copper, flows through the external circuit, and back again to the zinc of the first element. When the entire current flows through every member of the circuit, as in this arrangement, Ohm's law becomes:

$$\text{The strength of the current} = \frac{\text{sum of all the E. M. F.'s}}{\text{sum of all the resistances}}.$$

The resistance consists of the resistance of the elements and the resistance of the external circuit. If C be the strength of current, E the electromotive force of one element, R the external resistance, and l the internal resistance of one cell, then for the value for the intensity of current of one element,

$$C = \frac{E}{R + l}.$$

If now we connect six elements, as shown in our Fig. 99, we get:

$$C = \frac{6E}{R + 6l}.$$

Suppose now that the external resistance is so small compared with the rest that it may be neglected without appreciable error, then

$$C = \frac{6E}{6l} \quad \text{or,} \quad C = \frac{E}{l}.$$

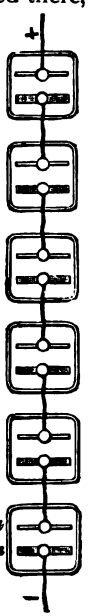


Fig. 99. — Elements in Series.

We obtain then for the intensity of current of the six elements in series, in this particular case, the same value as for one element—in other words: When we use an outer circuit of very small resistance, the intensity of the current is not increased by increasing the number of elements in series.

Let us consider what happens when the opposite is the case, and the external resistance is very great compared with that of the battery. We can neglect the resistance of the elements, and we then get:

$$C = \frac{6E}{R} = 6\,\frac{E}{R}.$$

From this we see that by arranging our six elements in series we increase the intensity of the current six-fold; it is advantageous, therefore, to arrange the elements in series when the resistance is considerable.

Connection of Cells abreast.—Elements may be connected with each other as shown in Fig. 100. Here all the copper plates are connected with one wire, and all the zinc plates with the other wire. Such a battery is equivalent to

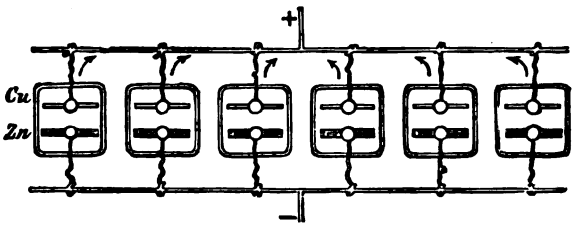


Fig. 100.—Elements in Parallel Connection.

one element with six times the original surface; the E. M. F. is not increased, but the internal resistance is diminished to $\frac{1}{6}$ of the original resistance, as the current flows through a cross section six times as large. This arrangement is

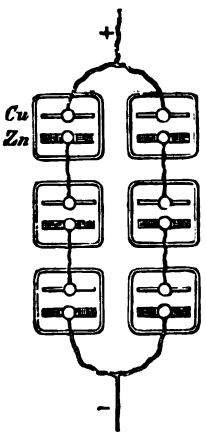


Fig. 101.—Elements in Double Circuit.

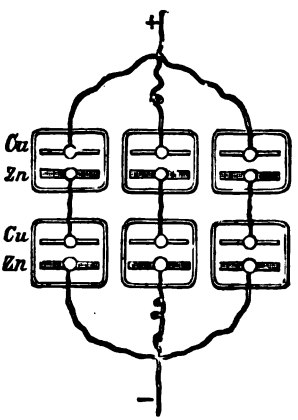


Fig. 102.—Elements in Treble Circuit.

known under the name of the parallel arrangement, or connection of cells abreast.

$$\text{The strength of current} = \frac{\text{E. M. F. (of one element)}}{\text{external resistance} + \frac{1}{6}\text{ internal resistance}},$$

$$\text{or, } C = \frac{E}{R + \frac{1}{6}l}.$$

Neglecting external resistance, we get:

$$C = \frac{E}{\frac{1}{6}l} = 6\frac{E}{l}.$$

When the external resistance is but slight, the current is increased by joining the elements in parallel arrangement. When, however, the external resistance is very

large, the internal resistance may be neglected, and we get the following equation, which is the same for one cell as for a number :—

$$C = \frac{E}{R}.$$

Hence the increase of elements in parallel arrangement does not increase the current when the external resistance is considerable.

The four equations which we have now obtained are of great importance, as they enable us to arrange the elements so as to obtain the most favourable

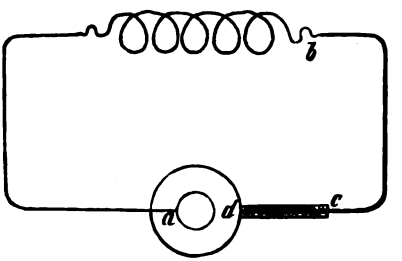


Fig. 103.—A Simple Circuit.

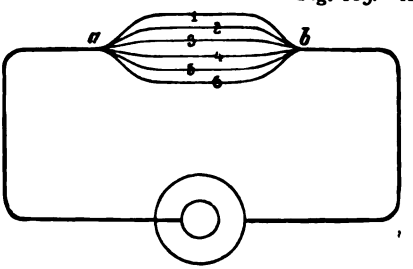


Fig. 104.—Divided Circuit.

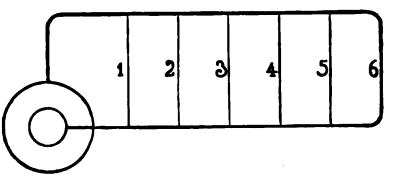


Fig. 105.—Divided Circuit.

results under different conditions regards the external circuit. Elements are arranged in series when the resistance of the external circuit is very great, but in parallel arrangement when the resistance is very small. Between the very great and very small resistance we may have intermediate conditions. In these conditions we make use of both the parallel and series arrangement. Figs. 101 and 102 represent such mixed combinations of elements.

For Fig. 100 we should obtain the following formula:

$$\text{Current} = \frac{3\,E}{R + \frac{3}{1}l}.$$

For Fig. 101 we get

$$\text{Current} = \frac{2\,E}{R + \frac{2}{3}l}.$$

Divided Circuits.—Up to the present we have discussed the arrangements of different elements with a single and simple external circuit; but the latter,

too, may be divided into branches or loops. The simplest arrangement is obtained when all the parts of the circuit lie so that the current without dividing can flow through them all. Fig. 100 represents such a circuit; here the separate parts *a b*, *b c*, and *c d* of the circuit are so connected with each other that they allow the current an undivided passage. The current here has to flow through one part after the other, and to overcome a resistance which is the sum of all the resistances of the separate parts in the circuit. The parts of a circuit may be arranged parallel as well as in series; Figs. 104 and 105 show such arrangement. In Fig. 104 the wire *a b* divides into six branches. In Fig. 105 two wires run parallel with each other from the battery, having other wires joining them across the circuit. Such arrangements are called divided circuits; and the laws of the resistances of such circuits were first elucidated by Kirchhoff. The sum of the currents in the different branches of the circuit must be equal to the current in the undivided conductor or circuit. Let us compare the behaviour of the branch currents with water flowing through a system of pipes shown in Fig. 106. Water flows through the pipes A B and D C in the direction indicated by the arrow-heads. The two pipes are connected with each other by a series of pipes 1 to 6, and water from A B is conducted through these six pipes to D C. The greatest amount of water will flow through that pipe which offers the least resistance, and the quantity of water that flows through the whole series of pipes must be equal to the quantity which flows through A B or C D (assuming that the same amount of water enters A that leaves D). If the pipes from 1 to 6 have all the same dimensions, then through each of these pipes equal quantities of water will flow; it follows that the resistance which the water from A B encounters, diminishes with the increase of the number of pipes between A B and C D. The resistance is reduced to $\frac{1}{6}$ when, instead of communication by one pipe, there are six of the same size. Here again the current of water is analogous to the electrical current. The current in the circuit represented in Figs. 104 and 105 depends upon the resistance of the separate branches 1 to 6. The passage of the current is facilitated by increasing the number of branches in the circuit, consequently the total resistance of the entire circuit is thereby proportionally lessened. If the branches from 1 to 6 are of equal dimensions, they will form together a resistance which will be $\frac{1}{6}$ of that of a single branch. If, however, we were to arrange the six one after the other, as shown in Fig. 103, we should increase the resistance six-fold. This difference, then, in the behaviour of

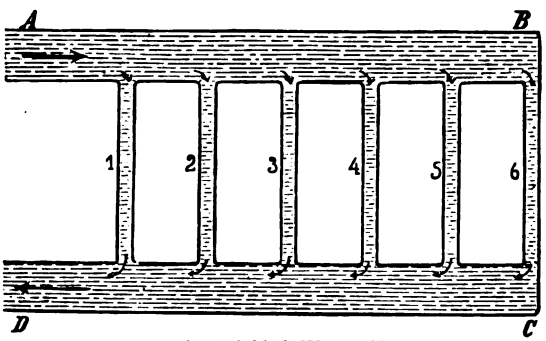


Fig. 106.—Divided Water Circuit.

conductors in a circuit, according as they are arranged in series or parallel, has to be as carefully considered in practical applications of electricity, as the arrangement of elements in a battery.

Let us call the power to convey the current either in the water circuit or electrical circuit the *conductivity* of the pipe or wire. Then conductivity is the reciprocal of resistance. The better the conductivity the less the resistance, and *vice versâ*. Now the following rule is evidently true. In a divided channel the conductivity of the whole is the sum of the conductivities of the branches. If C be the conductivity, and R the total resistance of the divided portion of the circuit, and c_1, c_2, etc., be the conductivities of the branches, and r_1 r_2, etc., the resistances of the same,

$$\text{then} \quad C = c_1 + c_2 + c_3 + c_4 + c_5 + c_6;$$

$$\text{hence} \quad \frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \frac{1}{r_4} + \frac{1}{r_5} + \frac{1}{r_6}.$$

If there are only two,

$$\text{then} \quad \frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}, \text{ or } R = \frac{r_1 r_2}{r_1 + r_2}.$$

Or, in words, *The joint resistance of a divided circuit is equal to the product of the two separate resistances divided by their sum.*

The branch of a divided circuit added to reduce the current in the other branch is technically called a *shunt.**

Cross Shunts.—Besides these simple arrangements of circuits and shunts, more complicated currents often become necessary, both for practical and experimental purposes. The behaviour of flowing water will again aid us in our explanations of some of these arrangements. The Figs. 107, 108, 109 represent three different systems of pipes. In each of the three figures water flows from *a* in the directions of the arrows, where it finds two pipes through which it can flow to *c*; into the branch pipe with the greatest cross section the greatest amount of water will enter, because least resistance will be offered. The quantity of water flowing at *c*, the undivided pipe, will be equal to the quantity of water entering at *a*, and the total amount of water flowing through *a b c* and *a d c* will be equal to the amount of water in the undivided pipe. In Fig. 107 the water flows in the direction of the great arrow to *a*, where it finds two pipes exactly like each other, *a b c*, *a d c*. The water will be equally divided here, and through each pipe half of the original amount will flow. The pipe *b d* connects *a b c* with *a d c*, and we have now to inquire how the water will flow in *b d*. The water flowing along *a b* and *a d* finds at *b* and at *d* the same conditions as to pressure. The pressures from *b* to *d* and from *d* to *b* oppose each other, and thus remain in equilibrium. The water in *b d* remains then at rest, because the resistances in *a b c* and *a d c* are divided at the points *b* and *d* in the same proportion. For the same reason the water in *b d* (Fig. 108)

* Such circuits are called by different electricians "divided," "parallel," "side by side, or "shunt" circuits.

will remain at rest, although the pipes *a b c* and *a d c* are here different from those of the previous figure, and offer a different resistance. The resistance of the parts of pipes to each other, however, remains the same as in the former case. The conditions will be altered in the arrangement shown in Fig. 109. Here the water divides at *a* into two unequal currents, the stronger of which *a d* arrives at *d*, where it meets a much smaller pipe, offering a greater resistance. The pressure will force water along the cross pipe *d b* beyond *b* in the direction from *d* to *b*. This motion will be favoured by the pipe *a b c*, which, being much broader, facilitates the farther flow. Hence such an arrangement as that shown in Fig. 109 will cause the water to flow in the direction from *d* to *b*.

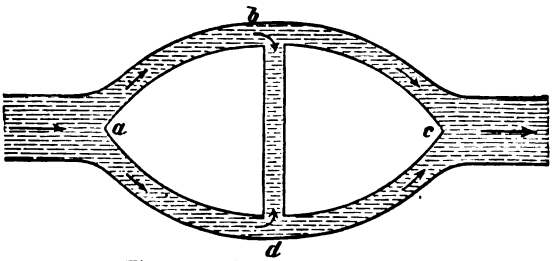


Fig. 107.—Cross Water Channel.

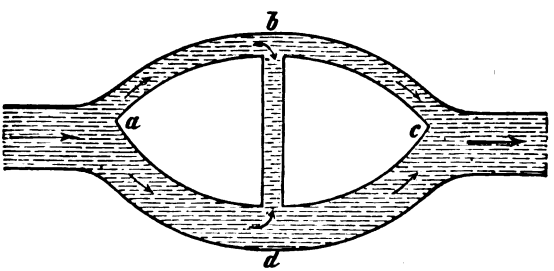


Fig. 108.—Cross Water Channel.

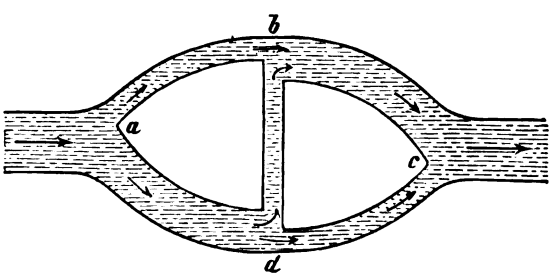


Fig. 109.—Cross Water Channel.

To complete the analogy we wish to trace, let us suppose the flow to be produced by a difference of level between the points *a* and *c* (Fig. 107). Suppose the stream to be flowing by two channels *a b c*, *a d c*, from a higher level at *a* (where the height above a certain initial level is v_1) to a lower level v_2 at *c*. For any point *b* in the first channel there is a point *d* in the second which is at the same level. If these two points are joined by a channel *b d*, there will be no flow along *b d*, because the ends are at the same level v. Let us now follow the analogous arrangement of a divided electrical current. If the potentials at *a* and *c* be v_1, v_2, and that at *b* be *v*, then there will always be a point *d* in *a d c*, having the potential *v*, and if this point be joined with *b* by a wire *b d* in which there is a galvanometer, there will be no indications of

current in $b\,d$. Now what must be the relations between the resistances $a\,b$, $b\,c$, $a\,d$, $d\,c$, that there may be no current in $b\,d$? By the extension of Ohm's law,

$$\text{the current in any part} = \frac{\text{fall of potential in that part}}{\text{resistance}};$$

$$\left.\begin{aligned}\text{hence current in } a\,b &= \frac{v_1 - v}{\text{resistance } a\,b}\\ \text{current in } b\,c &= \frac{v - v_2}{\text{resistance } b\,c}\end{aligned}\right\}$$

$$\left.\begin{aligned}\text{current in } a\,d &= \frac{v_1 - v}{\text{resistance } a\,d}\\ \text{current in } d\,c &= \frac{v - v_2}{\text{resistance } d\,c.}\end{aligned}\right\}$$

But when there is no current in $b\,d$, the currents in $a\,b$ and $b\,c$ are the same, and so are those in $a\,d$, $d\,c$:

$$\text{hence } \frac{v_1 - v}{\text{resistance } a\,b} = \frac{v - v_2}{\text{resistance } b\,c};$$

$$\text{or, } \frac{v_1 - v}{v - v_2} = \frac{\text{resistance } a\,b}{\text{resistance } b\,c.}$$

Similarly from the last two:

$$\frac{v_1 - v}{\text{resistance } a\,d} = \frac{v - v_2}{\text{resistance } d\,c};$$

$$\text{or, } \frac{v_1 - v}{v - v_2} = \frac{\text{resistance } a\,d}{\text{resistance } d\,c}$$

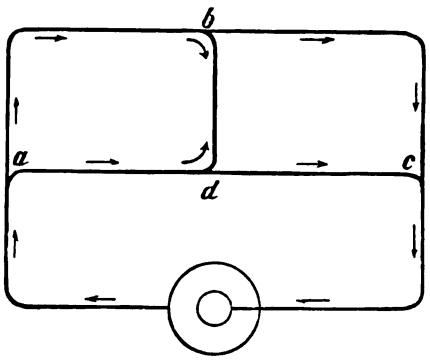


Fig. 110.—Cross Shunt.

$$\text{Therefore } \frac{\text{resistance } a\,b}{\text{resistance } b\,c} = \frac{\text{resistance } a\,d}{\text{resistance } d\,c}.$$

Fig. 110 represents a similar arrangement of the circuit to that of the system of pipes just now explained. The current, leaving the battery, divides at a into two branches, one branch flows through $a\,b$, the other through $a\,d$; at b and d the currents divide again; one portion flows through $b\,c$ and $d\,c$ back to the battery, the other portion flows from b to d, and d to b. The two currents flowing in $b\,d$, opposite to each other, will either weaken or entirely neutralise each other. The distribution of the current at a takes place in inverse proportion to the resistance of both branches: if this proportion for the two branches $b\,c$ and $d\,c$ remains unaltered, being the same as for the whole course $a\,b\,c$, $a\,d\,c$, the currents arriving at b and d will continue to flow along the same channels towards c. The bridge $b\,d$, therefore, will be without any current when between the four parts of the circuit the following proportion exists:

$$\frac{\text{resistance of } a\,b}{\text{resistance of } b\,c} = \frac{\text{resistance of } a\,d}{\text{resistance of } d\,c}.$$

If the resistances in one branch are equal, those in the other branch must also be equal.

Wheatstone's Bridge.—The principles laid down here give a most convenient method for measuring resistances. The instrument or arrangement by which it is applied is called Wheatstone's Bridge. Like all the so-called *nul* methods, which consist in reducing to nought the current in a particular circuit, it admits of great accuracy. The simplest mode of applying it is as follows: Let M (Fig. 111) be an unknown resistance, and N a measured resistance that may be adjusted to any required value. Let P and Q be two other equal resistances. Arrange M and N in one branch, and P and Q in the other branch of a divided circuit. Connect a galvanometer G with the junction of M and N on one side, and the junction of P and Q on the other. Adjust N until there is no current through G, then M = N.

Fig. 111.

Tables of Resistances and Conductivity.—It has been already stated that the resistance of a conductor depends upon its dimensions and the matter that composes it. Matthiessen, taking copper 1, found the following values:

	Specific resistance.
Silver	0·77
Gold	1·38
Aluminium	2·29
Zinc	2·82
Iron	5·36
Tin	6·76
Platinum	7·35
Lead	9·96
German silver	10·09
Antimony	18·07
Mercury	47·48
Bismuth	64·52
Graphite	1106·00
Gas carbon	2037·00

From this table we learn that of all metals, silver offers the least resistance, or, which is the same thing, silver possesses the greatest specific conductivity; we can easily arrange a table of conductivity by taking the reciprocals of the above:

Metal.	*Specific conductivity.*
Silver	100
Copper	77·43
Zinc	27·39
Iron	14·44
Platinum	10·53
Lead	7·77
Mercury	1·03
German silver	7.67
Graphite	·0693
Gas coal	0·0386

The relative conductivity of the principal liquids used in batteries may be seen from the following values found by Becquerel (conductivity of silver = 100,000,000):

	Conductivity.
Copper sulphate a saturated solution ...	5·42
Ordinary salt ,, ,, ...	31·52
Copper nitrate ,, ,, ...	8·99
Zinc sulphate ,, ,, ...	5·77
20 c.c. of H_2SO_4 in 220 c.c. water	88·68
Nitric acid	93·77

Resistance of liquids at different stages of concentration may be seen from the following table by Wiedemann (resistance of platinum = 1):

Sulphuric acid contained in 100 cubic centimetres water.		*Resistance.*
3·7	grammes	499,000
5·9	,, ...	283,500
11·42	,, ...	147,200
22·82	,, ...	88,070
45·84	,, ...	79,560
74·83	,, ...	108,300
183·96	,, ...	508,000

With salt solutions the resistance diminishes, as the amount of salt increases, the conductivity of pure water being very small. The behaviour of sulphuric acid is peculiar. Up to a certain point resistance diminishes with the increase of concentration, but beyond this point resistance increases with further concentration.

The influence of temperature upon a liquid may be seen from the following table after Wiedemann. The liquid tested was formed by solution of 187·02 grammes of copper sulphate in 1,000 c.c. water:

At	20·2° C.	the resistance	= 1,907,000
,,	26·2 ,,	,,	= 1,715,000
,,	37·5 ,,	,,	= 1,419,000
,,	51·5 ,,	,,	= 1,163,000
,,	60·0 ,,	,,	= 1,047,000
,,	75·6 ,,	,,	= 894,000

The resistance diminishes as the temperature increases, a result which is exactly opposite to what occurs with metals. Müller found the following values for copper wire at different temperatures:

At 21° C.	the resistance	= 864
,, a dull red heat ...	,,	= 2,100
,, a red heat ...	,,	= 2,450
,, a bright red heat	,,	= 3,300
,, a white heat ...	,,	= 4,700

When the wire was again cooled to 21°, its resistance was 910.

Conductivity for carbon increases with the temperature, thus agreeing with the action of liquids. Professor Ayrton thinks this seems to indicate that carbon may be a compound, and not an element. Mercury follows the other metals—that is, conductivity decreases and resistance increases with temperature.

Siemens' Unit of Resistance.—To determine the resistance of a conductor we must have some unit. Jacobi's unit of copper wire 1 metre in length and of 1 millimetre in cross section proved unsatisfactory, because the resistance of copper is considerably altered by even the slightest impurities; for this reason Siemens chose the mercury unit, which is much used, especially in Germany. It consists of a column of mercury one metre in length and one square millimetre in cross section. Siemens' unit is manufactured by the firm of Siemens and Halske, of Berlin. When it would be inconvenient to use the mercury, copies of the mercury unit in other metals may be used; German silver is used for the purpose, the length of the unit being accurately calculated to agree with the mercury unit. Fig. 112 represents such a unit. The German silver wire is coiled and placed in a cylindrical box (the cover of which is omitted in the diagram); the ends of the wire are well connected by means of screws with the metal bars *a b* and *c d*. The screws *b* and *d* serve the purpose of binding screws for the wires of the circuit. The adjoined pieces *a* and *c* are used when it is thought desirable to make the connections by dipping the ends into mercury cups instead of by binding screws.

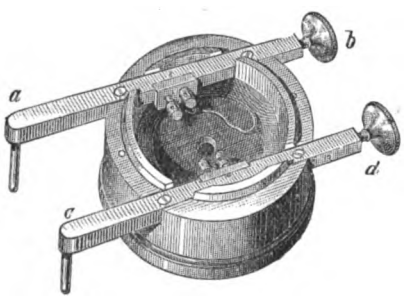


Fig. 112.—Box, with Unit of Resistance.

Instruments for the Measurement of Resistance.—With the help of such a unit it would be very easy to measure the resistances of different wires by a Wheatstone's Bridge. It is, however, often convenient to have an instrument which will furnish an adjustable measured resistance with which we can compare the wire under examination. Such an instrument is the Rheostat, which has been graduated according to the unit. One of these instruments is represented in Fig. 113. The wire, having a known resistance, is wrapped on a cylinder of wood turned by a handle. The movable terminal carried by the thick rod *s s* presses by means of a spring against the wire, which acts like a screw when the handle is turned, and moves this terminal along the rod. Any number of turns and fraction of a turn of the wire can thus be brought into the circuit. The rheostat shown here is easily injured, and has many faults; it is therefore not used now so much as formerly. Poggendorff's rheochord, represented in Fig. 114, is a more reliable instrument. The two platinum wires *a* and *b* are fastened at one end to the small copper blocks *d* and *c*; at the other end *e f* the wires are fastened to silken cords, which run over the rollers *g*, and

carry weights for the purpose of giving the platinum wires a uniform stretch. K is a sheet-iron box filled with mercury, which has the sides through which the wires pass made of glass. The instrument is inserted in the circuit by

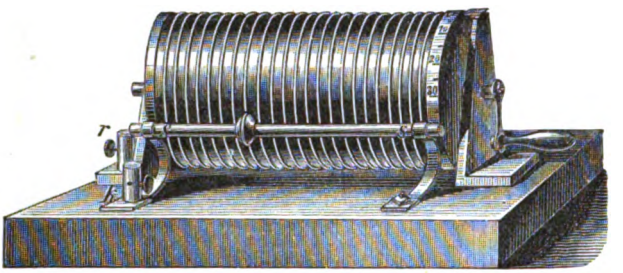


Fig. 113.—The Rheostat.

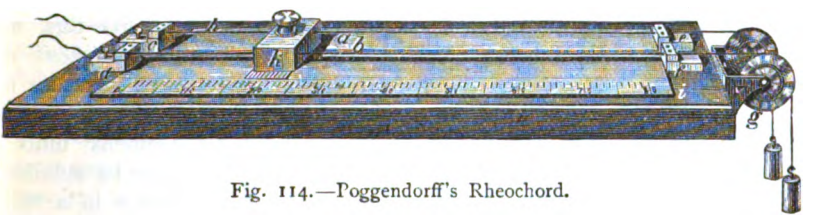


Fig. 114.—Poggendorff's Rheochord.

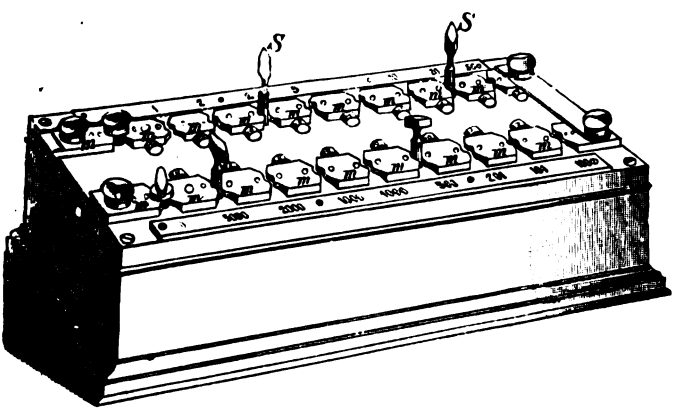


Fig. 115.—Resistance Box.

means of the screws *d c*. The current enters through one of the screws, passes through the wire up to the box, through the mercury to the next wire, and leaves the apparatus through the other screw. It is easily seen that by moving the box along the two platinum wires different lengths of wire can be inserted; in order to measure these, the instrument has a graduated scale. It is, however, difficult to obtain the wires perfectly uniform through their whole length.

Resistance Boxes.—If greater resistances are to be measured, other kinds of apparatus must be used. Such an instrument is Siemens' resistance box, represented in Fig. 115. Fig. 116 represents the arrangement of two resistance coils of such a box. The ends of a coil of known resistance are connected with brass pieces *m m*, which are divided from each other by a small space, and have each of them a semi-cylindrical bore. If now the current enters one of these brass pieces it cannot flow to the next before it has gone through the coil between them; but the current can pass directly from one brass piece to the other when the plug s is inserted. The current in Fig. 116 would have to flow through the two resistance coils first before it could reach the third piece of brass. In the resistance box (Fig. 115) a series of such resistance coils of increasing resistance is arranged. The resistance of each coil is exactly determined, and the coils are arranged with Siemens' units, in the following manner:

1. Row ...	1	2	2	5	10	10	20	50
2. Row ...	5,000	2,000	1,000	1,000	500	200	100	100

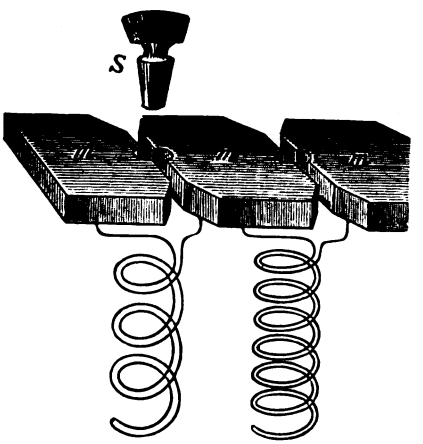


Fig. 116.—Resistance Coil and Plug.

With an arrangement like this, resistances from 1 to 10,000 Siemens' units can be measured. To measure fractions of a unit, resistance coils of 0·1, 0·2, 0·2, and 0·5 Siemens' units are added, or the unit may be subdivided by making it one branch of a Wheatstone's bridge. When the resistance box (Fig. 115) is used, care ought to be taken that all the metal parts are bright, especially the bores, and that the plug is firmly placed into the hole with a screwing motion.

Galvanometers.—To determine the resistance of a conductor we need a galvanometer. Various constructions and forms of galvanometers are in use, but we shall find it sufficient for our purpose at this point to describe the tangent galvanometer, shown in Fig. 117. The copper ring *r*, terminating in the binding screws K_1 K_2, is placed on a wooden frame, as represented in the figure. On the metal pillar, insulated from the ring, is the box *b* and the magnetic needle, which is suspended by means of a cocoon thread from the tube *f*. The box *b* has a graduated circle, the centre of which coincides with the centre of the copper ring. The graduation of the scale is so arranged that the zero point lies in the plane of the ring.* Before using the instrument, then, we must adjust

* In many instruments the needle is a small lozenge-shaped piece of steel, and to indicate the angle of deflection a long light pointer of drawn-out glass is fixed across it. In this case the zero-point is 90° from the plane of the ring, for it is not the needle but the pointer that indicates the deflection.

it; that is, we must turn the ring until the needle points to 0. When we connect the wires of the source of electricity with K_1, K_2, the current will flow round the copper ring, and cause the needle to be deflected. The earth's magnetism tends to bring the needle back again to its former position of rest, but after a few oscillations the needle at last remains stationary at the position in which the effects of the current and of the earth's magnetism balance each other. The deflection of the needle will be the greater the greater the current is, and for equal currents the needle will show the same deflection. When the needle is small, so that it moves within a space that may be considered a uniform "field" due to the current, the strength of the current is directly proportional to that function of the angle of deflection called the tangent. When we know the angle, a book of trigonometrical tables has to be consulted to find the tangent. Currents proportional to the numbers 1, 2, 3, etc., produce deflections whose *tangents* are as the numbers 1, 2, 3, etc. If C be the strength of current, r the radius of the ring, H the horizontal component of the earth's magnetic force, and δ the angle of deviation, then

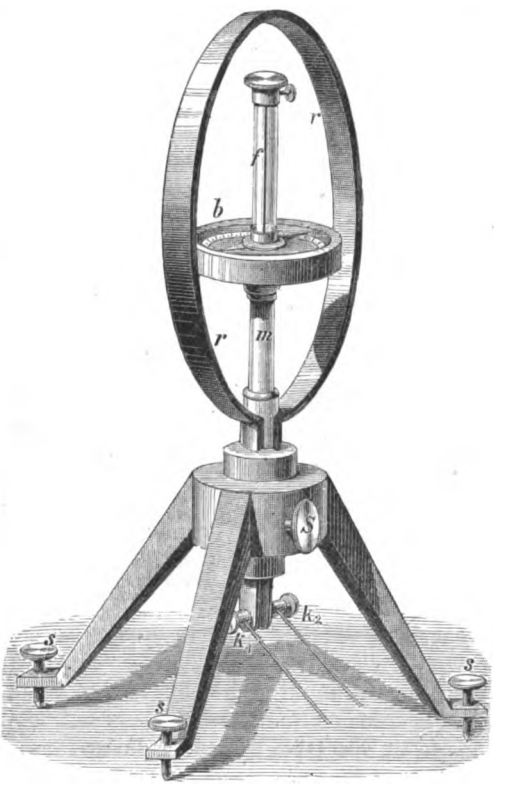


Fig. 117.—The Tangent Galvanometer.

$$C = \frac{r}{2\pi} H \tan \delta$$

or $C = a \tan \delta$.

where a is a constant depending on the size of the ring and the earth's magnetic force.

Measurement of Resistances.—We are now in a position to measure the resistance of any wire. We may make the experiment in many ways, one of the simplest being as follows: A complete circuit is made with a constant galvanic element, a galvanometer, and the wire whose resistance is to be taken. The deflection of the needle is noted, and the wire to be measured removed, and in its stead is placed a rheostat, or resistance box. Resistance is now added until the needle shows the same deflection as before. This resistance will be equal to the resistance of the wire under examination. This method of

determining the resistance (called the method of substitution) has several defects. Between the first and second reading a certain time passes, during which the E. M. F. and internal resistance of the battery might have undergone some change. We may partly eliminate the error by again inserting the resistance to be measured, and taking the mean of the two observations.

The method with Wheatstone's bridge is not open to this objection. We have seen that in an arrangement like that represented in Fig. 110, the connecting wire *b d* is without a current when the resistances of the remaining four wires stand as follows:

$$\frac{\text{resistance of } a\,b}{\text{resistance of } b\,c} = \frac{\text{resistance of } a\,d}{\text{resistance of } d\,c}.$$

Fig 118 shows us how to use this principle and to measure resistances with the bridge. The screws *a b c d* are fixed at the corners of a rhombus; the screws, *e g h* in two sides meeting at a point *d*. The wires *a b* and *b c* are equal to each other, and possess the same resistance; the wires *a e*, *f d*, *d g*, and *h c* are also equal to each other, and have the same resistance. The connecting wire *d* B *b* will be without a current when the resistances of the wires *a b* and *b c* are to each other as all the resistances between *a* and *d* are to all resistances between *d* and *c*. A galvanometer is inserted at B; the wire under examination W is inserted between *e* and *f*; and, lastly, any rheostat or box of coils R between *g* and *h*. When in this circuit the connecting wire *d* B *b* is to be without current, the following proposition must be true:

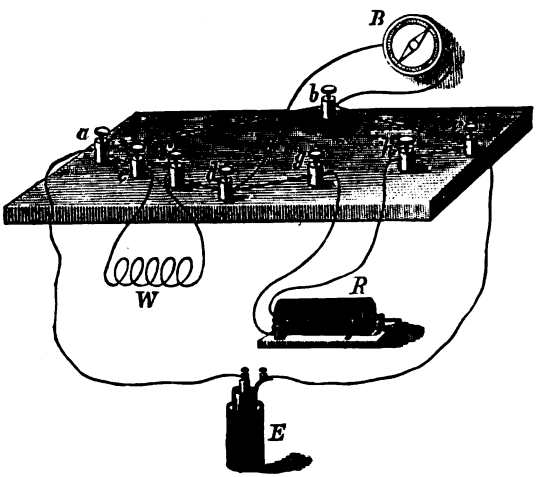


Fig. 118.—Wheatstone's Bridge.

$$\frac{\text{resistance of } a\,b}{\text{resistance of } b\,c} = \frac{\text{total resistance between } a \text{ and } d}{\text{total resistance between } d \text{ and } c}.$$

We have already pointed out that when the wires *a b* and *b c* are of the same resistance, and no current passes through *d* B *b*, the sums of the resistances between *a d* and *d c* must be equal. Again, in this case, since the wires *a e*, *f d*, *d g*, and *h c* are equal to each other, the resistance of w must be equal to the resistance between *g* and *h*.

Another way of using the bridge is to stretch the wire *a b c* (usually a

german silver wire) over a graduated scale, and to make *b* a "slider" or binding screw that makes contact with the wire, but may be moved to any part of it. Then R may be a known resistance not necessarily equal to W, and when *b* is moved until there is no deflection of B we shall have,

$$W : R \text{ as the length of } a\,b \;:\; \text{the length of } b\,c.$$

To Measure the Resistance of Liquids.—To determine the resistance in liquids, the above methods cannot be employed; liquids being decomposed by the electrical current. Horsford has shown how to compensate for the E. M. F. generated by the products of decomposition. He joins up in the same circuit, beside the galvanometer and rheostat, a vessel containing the liquid, and supplied with suitable electrodes. The two electrodes are first immersed at a fixed distance from each other in the liquid. The deflection of the needle will then indicate the difference of the E. M. F. of the battery and of the liquid under examination, for the resistance of the rheostat and that of the column of liquid lying between the electrodes. The two electrodes are now removed farther from each other, so that the column of liquid becomes larger, and also the resistance. The needle will consequently show a smaller deflection. If now by means of the rheostat such a resistance is removed as will restore the original deflection, the resistance removed will be equal to the resistance of the column of liquid added.

Measurement of Electromotive Force.—The E. M. F. of a galvanic element may be ascertained by taking the difference of potentials at the two poles by a Thomson's quadrant electrometer. But more indirect methods of determination are, as a rule, more convenient. We may measure the resistance and current of the element, and calculate the E. M. F. from these values, by means of Ohm's law. As we required a unit for measuring resistance, we require a unit for measuring E. M. F. In Germany the E. M. F. of a Daniell's element is much used as a unit.

The E. M. F.'s of two cells—a Grove's and a Daniell's, for instance—may easily be compared by the following method. Let E_1 and E_2 be the cells to be compared.

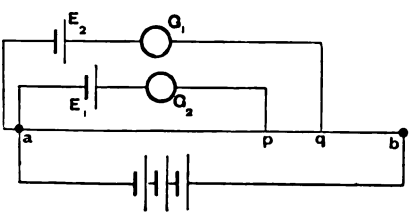


Fig. 119.

Stretch a German silver wire *a b* about a metre long over a scale. Take a battery the E. M. F. of which is known to be greater than either E_1 or E_2 and join it up with *a b*, the zinc being towards *a*. Join E_1 and E_2 with galvanometers G_1 and G_2 in their circuits, so that the wires from the zincs come to *a*, and the positive wires to movable points *p* and *q*. Move *p* along *a b* until there is no deflection of G, and then do the same with *q*. Then E_1 is equal and opposite to the D. P. between *p* and *a*, and E_2 to the D. P. between *q* and *a*. But the fall of potential along *b a* varies as the resistance (Ohm's law), and therefore as the length. Hence $E_1 : E_2$ as the length *a p* : the length *a q*.

At the Congress in Paris, in 1881, it was agreed to adopt certain practical units

which are so related that Ohm's law, and other laws connecting electrical quantities, may receive their simplest expression when the measurements are expressed in these units. For instance, the units of quantity and of strength of current are so related, that when the former passes through a cross section of the circuit in a unit of time, the current caused has the unit of the strength of current According to this plan we must consider the unit of E. M. F. that which gives to the unit of electrical quantity the unit of current.

If we know the unit for the strength of current as well as the unit of E. M. F., we can easily find the unit of resistance. According to Ohm's law, we have,

$$\text{unit of resistance} = \frac{\text{unit of the E. M. F.}}{\text{unit of strength of current}}.$$

We shall subsequently explain the connection of the practical units with the unit of length (the metre), mass (the gramme), and time (second), that is to say, with the C. G. S. system of units. For the present it will suffice to name these units, and indicate a mode of producing them. As a rule the practical units receive the names of great physicists.

The unit quantity is the *coulomb*. It is the quantity that sets free ·000010 5 gramme, or ·000162 grain of hydrogen. When the coulomb flows past any section of a circuit per second, the current has a unit strength. This unit current is called an *ampère*. (Anglicised ampere). A current of one ampere, if used to set free hydrogen from water, liberates ·000010 5 grammes a second; or if to decompose a silver salt, ·0175 grain of silver per second.

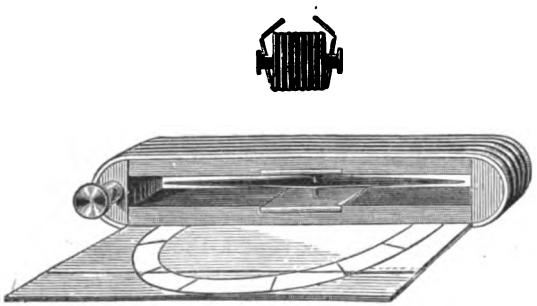


Fig. 120.—A Multiplier.

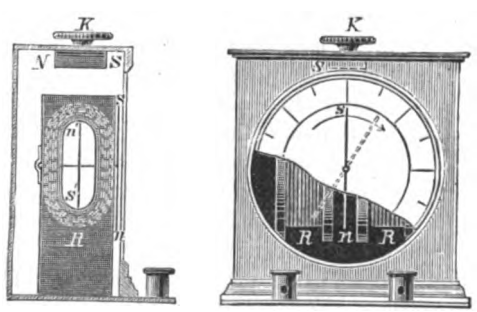


Fig. 121.—The Vertical Galvanoscope.

The unit difference of potential is called the *volt*.

The E. M. F. of an element is measured by the difference of potentials at the poles of the unclosed element. If, therefore, we have an element whose difference of potentials is = 1 volt, we may consider the E. M. F. of this element to be the unit of E. M. F., and call it 1 volt. If we compare the E. M. F. of a Daniell's cell with the volt, we find that 1 Daniell

has an E. M. F. of 1·12 volts. Bunsen's element has an E. M. F. of 1·95 volts. If now in a circuit resistance is so regulated that by an E. M. F. of 1 volt the strength of the current becomes one ampere, we have the amount of resistance which has been chosen for the unit, and which is called the *ohm*. Volt, Ampere, and Ohm, according to Ohm's law, have the following relation to each other:

$$1 \text{ ampere} = \frac{1 \text{ volt}}{1 \text{ ohm}}$$

The ohm is equal to 1·0493 S. of Siemens' unit of resistance, and is the resistance of a column of mercury at 0° C., one square millimetre in section, and 106 centimetres in length.

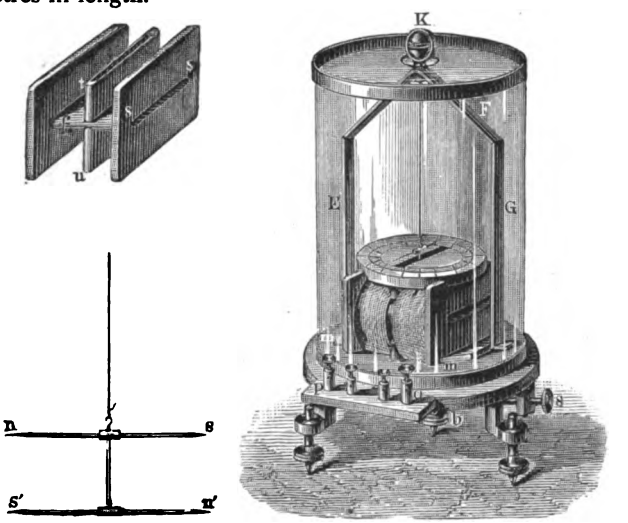


Fig. 122.—The Astatic Galvanometer.

Instruments for detecting the Presence and Direction of a Current.—When the direction and approximate strength of a current only are required, very simple apparatus, known under the name of galvanoscopes, are used. To roughly estimate the strength of a current, an instrument as shown in Fig. 120 is frequently used; it consists of a wooden frame which has a few turnings of a thick wire. We may term it a multiplier.

A more sensitive instrument is the vertical galvanoscope (Fig. 121). Here two magnets are placed parallel to each other so that the north pole of one is over the south pole of the other. Such an arrangement of the needle is known as astatic. The earth's magnetism has very little effect upon it, and this arrangement shows greater sensibility to currents. It is, however, difficult to make two needles so that their magnetisms shall be of exactly equal strength. Hence, to compensate for the effects of the earth's magnetism, a magnet N S is introduced which can be adjusted by means of the screw K.

To measure very weak currents and take very accurate readings, even this instrument is not sufficiently sensitive, and the instrument employed is the multiplier, shown in Fig. 122, which may be called a differential astatic galvanometer. It has two coils that may be connected, so that the same current goes round both in the same direction or in different directions, or they may be used separately. The frame for the coils and the astatic needle-pair are separately drawn. The frame with the coils is fastened upon a horizontal metal disc, which moves upon the bottom plate, and is maintained in a horizontal position by means of three levelling screws. The screw S is to arrest the motion of the disc with the coils when the zero of the scale is brought into the magnetic meridian. One of the coils has about 100 turnings; the other about 10,000. The four binding screws P to O are in connection with the ends of the two coils. The needle is hung from the metal support E F G. The screw K is for the purpose of raising or lowering the needles. The number of windings which must be given a multiplier depends entirely upon the purpose for which it is to be used. When used in a circuit of small resistance, fewer turnings of wire will suffice, whilst when used with great resistance a coil of many turnings has to be used.

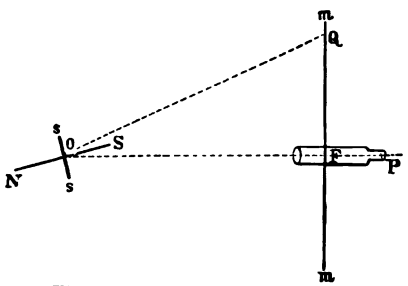


Fig. 123.—The Mirror and Scale.

The greatest accuracy in measuring the deflection of the needle is obtained by taking reflected readings upon a lengthened scale. Before describing a reflecting galvanoscope, we will explain the principle on which it acts. *s s* (Fig. 123) represents a small mirror. If a ray of light in the direction Q O falls upon this mirror, it will be reflected in the direction O P. *m m* is some kind of scale, say a metre (divided into millimetres), and F is a telescope; an eye looking through F will see the division at Q. Another way of using the scale is to replace the telescope by a lamp which will send a beam of light first to the mirror and thence to the scale. From the drawing it may be seen that the spot of light will move farther along the scale the greater the angle through which the mirror is turned. It will be noticed also that very slight turnings of the mirror correspond to very considerable distances on the scale, and these distances become greater the farther the scale and telescope are removed from the mirror. Suppose the mirror *s s* fastened to the magnet N S, even the slightest motion of the magnet will be recorded by the spot of light reflected on to the scale from the mirror.

The reflecting galvanometer originally constructed by Weber is shown in Fig. 124: ff^1 are the termini of coils; N the needle; *k k* the box containing the mirror. The instrument has since undergone many alterations, although the principle has remained the same. Wiedemann somewhat improved upon it by giving it a mirror of steel, which he then magnetised; so that mirror and

magnet consisted of one piece. In England and America a form devised by Sir William Thomson is chiefly used. Fig. 125 represents an instrument manufactured by the firm of Siemens and Halske, of Berlin, in which the magnet M has a peculiar form; it is made of a hollow steel cylinder, open at one end, and closed by a

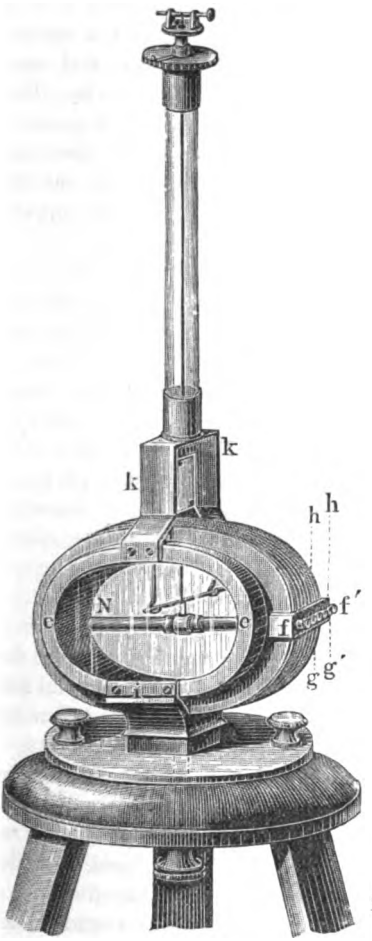


Fig. 124.—Weber's Reflecting Galvanometer.

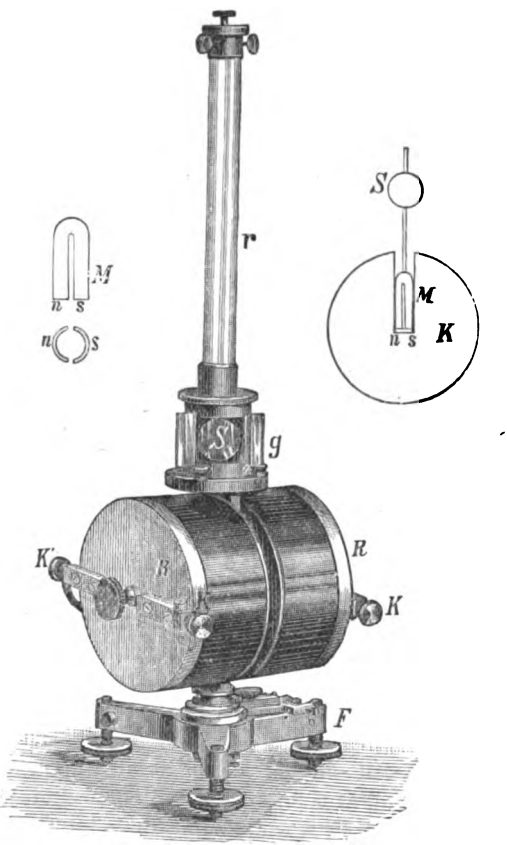


Fig. 125.—Siemens and Halske's Galvanometer.

hemisphere of the same metal at the other end. This cylinder is cut open through its length, and magnetised in such a manner that the north and south poles *n s* are at the open end. The bell magnet (as it is called) has this advantage, that without diminishing the magnetic moment, the moment of inertia becomes less. The magnet hangs in the cylindrical bore of a massive copper ball K, and is connected with the mirror s by means of a small rod of

aluminium. R R are the coils, and K K the screws. The frame F has levelling screws for adjustment. It has been stated that the magnet swings in a more or less massive copper case; to understand the reason for this, we must here give an explanation which will be repeated more fully at a later stage. It has been stated that electrical currents are generated in a closed circuit near a moving magnet. These currents either attract or repel the poles of the magnet, according to their direction; they attract when the magnet moves away, and repel when the magnet approaches. In both cases they resist the motion. This soon causes the magnet to cease swinging and assume its fixed position. This deadening of the oscillation is the more effective the less the resistance the neighbouring conductor offers to the induced electrical currents, and this is the reason why a magnet ought to be surrounded by a thick mass of copper.

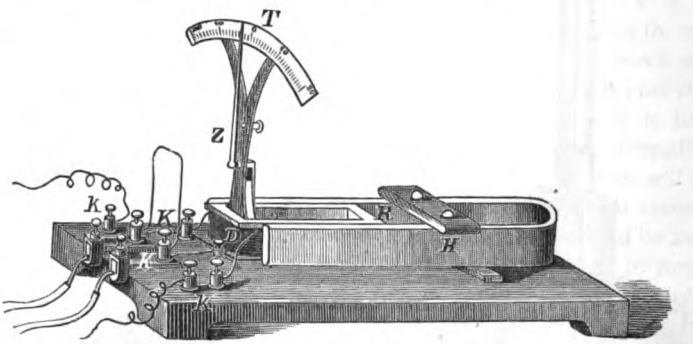


Fig. 126.—Deprez's Galvanometer.

The instruments we have already described enable us to detect even the weakest currents; but for quick and direct measurements of such powerful currents as electrical industry makes use of now-a-days, they are insufficient. Apparatus for such purposes has been constructed by Deprez, Ayrton, Perry, and others.

Galvanometers for Strong Currents.—Deprez's galvanometer for strong currents is represented in Figs. 126 and 127. H is a horse-shoe magnet; R a wooden frame, which has a copper band, and several turnings of wire D. One set of binding screws K is in connection with the copper band, and the other binding screws K_1 are in connection with the coil. Inside the frame is a soft iron plate S, which has ten incisions on each side, and moves round a horizontal axis upon two knife edges. One of these edges is seen at A in Fig. 127. The parts of S become magnetised by induction of the magnet, whenever an electrical current flows round them, and are deflected from their position of rest. When the galvanometer has no current the little weight G brings the iron plate back into its first position. The motion of the plate is indicated by the pointer Z, which moves along the scale T. To make it more convenient for use, the instrument is usually gauged in amperes; that is to say, it is determined by experiments in what proportion the divisions in the scale stand to an ampere.

The ammeter (ampèremeter) of Ayrton and Perry also gives direct readings in amperes. A very light magnetic needle C (Fig. 128) can move freely in the magnetic field formed by the armatures N and S of the magnet A B. The two coils D D consist each of ten wires, and are so arranged that each deflection of the needle is directly proportional to the strength of the current. The wires are in connection with a cylinder having contact springs (Fig. 129). By simply turning this cylinder, the sixty wire turnings of the instrument can be arranged either in series or parallel. The instrument is very sensitive, and at the same time is easily graduated at any time. In both Deprez's and Ayrton and Perry's instruments the influence of the earth's magnetism is reduced to a minimum by having the needle in a strong magnetic field. Ayrton and Perry have constructed a voltmeter on a similar principle to that of their ammeter. The difference is that the voltmeter has coils of 400 ohms resistance, and measures the difference of potentials between two points in volts, whereas in the ammeter the resistance in series is about 0·3 ohms and parallel 0·005, the latter being more than one-hundredth of the former, in consequence of the resistance of the small leading wires inside the instruments.* The ammeter is calibrated in series and generally used in parallel circuit, whereas the voltmeter is calibrated in parallel circuit and used generally in series, and then indicates from 1 volt per degree in some instruments to 5 volts per degree in others, the total deflection of 45° in the latter case corresponding with 225 volts. But just as the ammeter can be conveniently used in series, when testing the comparatively small currents passing through a single incandescent lamp, so the voltmeter may be used in parallel circuit for testing electromotive forces of two or three volts, such as, for example, the electromotive forces of one or two Faure's accumulators. To calibrate the voltmeter, the commutator is turned to *parallel*, and a current sent through the instrument by a cell of known electromotive force E, but of unknown resistance, producing, say, a deflection of D_1; the plug attached to the instrument is now taken out, which has the effect of adding a resistance of 4 ohms, and

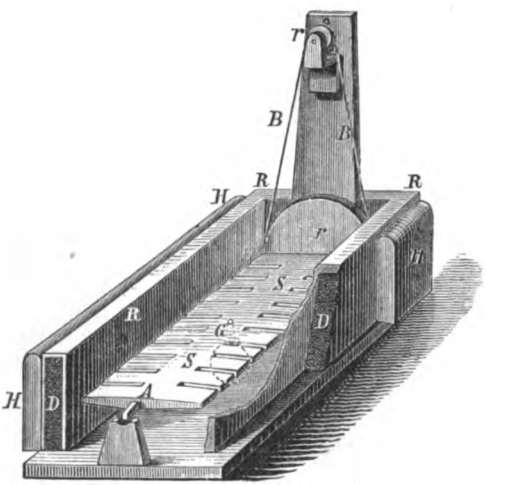


Fig. 127.—Deprez's Galvanometer.

* The voltmeters are now made with each coil having a resistance of 200 ohms, so that the instrument in series has a resistance of 2,000 ohms, and in parallel circuit, 20 ohms, the resistance coil being also of 20 ohms.

a second deflection D_2 obtained. From this it can easily be proved that an electromotive force $10\ \frac{D_1 - D_2}{D_1\ D_2}\ E$ volts between the terminals of the instrument will produce a deflection of 10° when the commutator set to parallel, or 1° when to series.

Keys and Connectors.—In tracing the effects of currents we shall have occasion to mention connectors of various kinds. A *key* is an instrument which is used when the circuit has occasionally to be closed or broken. A *plug* is better than a key when a portion of the apparatus has to be thrown out or brought into the circuit at will. (*See* resistance box, Fig. 115.) A *switch* is a kind

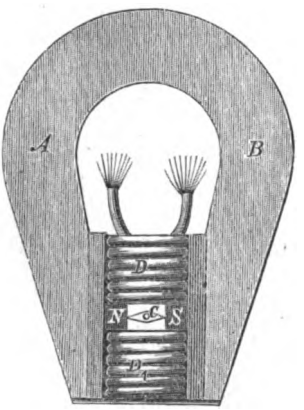


Fig. 128.—Ayrton and Perry's Ammeter.

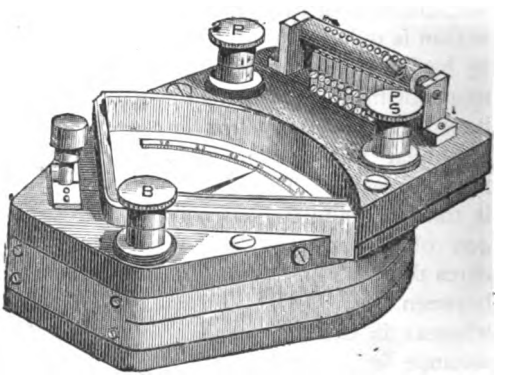


Fig. 129.—Ayrton and Perry's Ammeter.

of key which enables us to divert a current from one wire to another. A *commutator* enables us to send a current through a given instrument, first in one direction, then in the other. We frequently require to make and break contact suddenly, and it would be very troublesome to have to remove the wires to effect the change. Instruments are used for the purpose called contact-breakers.

Fig. 130 represents the instrument known as Dubois' key, in which contact is made by a brass piece *c*, that can be moved in the direction shown by the dotted lines.

Pohl's gyrotrope, or commutator, is shown in Fig. 131. Six hemispherical holes are made in a board, and filled with mercury; those numbered 5 and 2 and those numbered 3 and 6 are connected with each other by means of copper wire. Into 1 and 4 dip pointed copper bars *m* and *n*, which have a glass bar separating them. The two metal rods *c d* and *a b* are arranged in arcs as shown in the figure. When in use, the poles of the battery dip into 1 and 4. Into 2 and 3, or 5 and 6, dip the poles of the circuit s; when, as in the diagram, 2 and 3 are in contact with the circuit, the current from the battery in 1 will reach 2 through *m a*, pass the circuit s, and reach 3; pass *c* and *n*, reach 4, and will then flow back again to the battery. If now we want to change the direction of the current,

all we have to do is to let *d* and *b* dip into 5 and 6. The current now flows from 1, through *m* and *b* into 6, passes by means of the copper wire into 3, flows through the circuit backwards into 2, through the second copper rod (having one side insulated) into 5, and through *d* and *n* back to the battery.

The same result is obtained by Ruhmkorff in a different manner by means of his commutator, shown in Fig. 132. w is a cylinder, consisting of a non-conducting substance, such as ebonite, having a semi-cylindrical plate of copper round

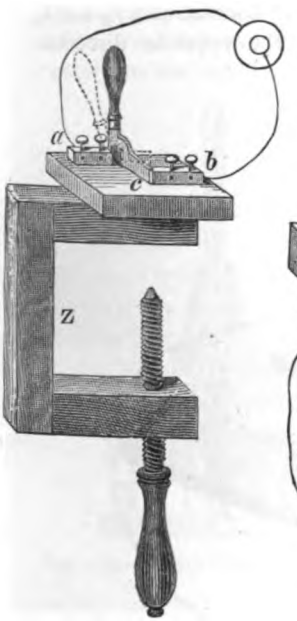


Fig. 130.—Dubois' Key.

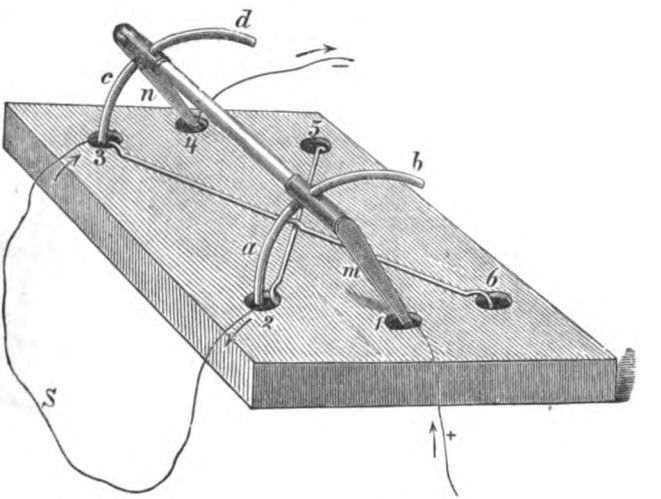


Fig. 131.—Pohl's Commutator.

it. The way in which the copper plate is fastened to the cylinder is shown in the separate portion of the diagram. The axis of the cylinder consists of the two pieces *e* and *g*, which are insulated from each other. The copper plate is fastened by means of metal screws to the cylinder in the following manner: S_1 and S_2 are in contact with the metal axes *e* and *g* respectively, while the remaining two screws only reach the insulating substance of the cylinder. The screw S_1 connects the copper plate K with the axis *e*, and the screw S_2 connects the copper plate K_2 with the axis *g*. The binding screws *a* and *b* are fastened upon the copper springs f_1 and f_2. When the cylinder is turned so that the two copper plates are at the top and bottom respectively, both springs lie upon the insulating cylinder, and hinder the current from passing; in other words, they break contact. When the cylinder is now turned so that the two copper plates stand horizontally or at the side, one spring lies upon one of the copper plates, and the current may pass through the commutator in one or

the other direction. This instrument, therefore, may be used as contact-breaker as well as current-reverser. When the spring f_1 is in contact with k_1, and f_2 with k_2, the current takes the following route. It enters at a, passes through the copper plate k_1 and the screw s_1, and then reaches the axis e, along which it flows to the metal support and the screw c. It then flows through the circuit, enters the axis g at d through the other support, then to the screw s_2, to k_2, to f_2, and finally through the screw b back again to the battery. If now we give the cylinder a turn of 180°, so that k is in contact with f_2, and k_2 with f_1, the current will flow through the circuit in the opposite direction.

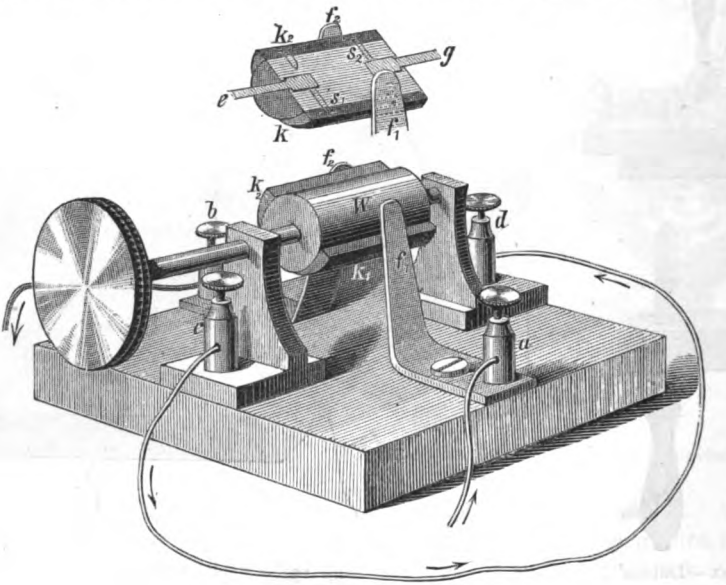


Fig. 132.—Ruhmkorff's Commutator.

The current reaches the instrument again at a, enters f_1, which is now connected with k_2, passes then from f_1 to the screw s_2, from there to g and d, and then through the circuit c, the axis e, the screw s_1, the copper bolster k, the spring f_2, the screw b, and back again to the battery.

In devoting our attention to the effects of the galvanic current, we may divide them into two classes: effects within the circuit and effects without it.

EFFECTS OF A CURRENT WITHIN THE CIRCUIT.

Heating Effects.—A short time after the discovery of the galvanic current, it was observed that a wire which has a current passing through it may become considerably heated. Davy (1778-1829) knew that the heating becomes the more noticeable the stronger the current and the greater the resistance of

the wire; but exact investigations were first made by Joule (1841). To show that a wire becomes heated when a current passes it, he made use of the apparatus shown in Fig. 133. The thermometer *s* has, instead of the ordinary bulb for the mercury, a tube *g* bent in spiral form. The lower end of this tube *p* has a platinum wire fused into the glass, and connected with the binding screw k_1; a platinum wire is also fused into the glass at p_2, and connected with k_2. When the poles of a galvanic battery are attached to k_1 and k_2, the current will have to pass through the mercury in *g*. The mercury, becoming heated, will expand, and the extent of the expansion will be shown by the rising of the mercury in the tube *s*. Joule also measured the heating effect of a current

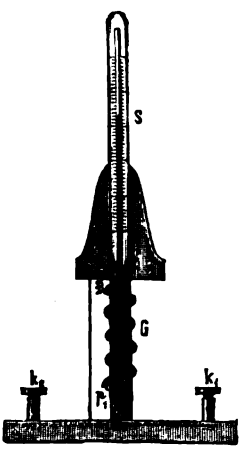


Fig. 133.—Joule's Current Calorimeter.

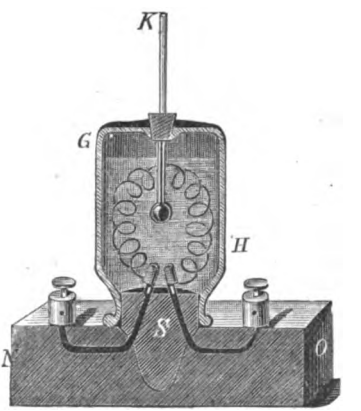


Fig. 134.—Lenz's Current Calorimeter.

on a wire in other ways. One of his plans consisted in winding a wire round a very sensitive thermometer, and immersing it in water. By this means he found the following to be the law: the heat generated in a conductor by a current is directly proportional to the resistance of the conductor. He further thought that the heat generated in a certain wire at the same time by a current changing its strength must be proportional to the square of the strength of current. Experiments made by others confirmed this conclusion, and the law, known under the name of Joule's law, is as follows: the quantity of heat generated in a certain time in any part of the circuit is directly proportional to the resistance of this part of the circuit and to the square of the strength of the current. Experiments made by Becquerel and Lenz confirmed Joule's law; the apparatus Lenz used for the experiments is shown in Fig. 134. It is an inverted bottle and stopper. The stopper S is fastened upon the support N O, and the bottle G H is made to fit it tightly. Two platinum wires are passed through the stopper, terminating in little cubes of platinum; to these platinum cubes a platinum spiral is fastened. The bottle G H is

filled with alcohol (water being too good a conductor of electricity for this purpose), and a very sensitive thermometer K is tightly fitted into the bottle. By this apparatus it was proved that Joule's law holds good, not only for solid bodies, but for fluids also. If C be the strength of the current and R the resistance between two points of the current having a difference of potential E, then the mechanical equivalent of the heat produced per second between these points is $C^2 R$ or C E (for by Ohm's law C R = E).

From Joule's law we can make an interesting deduction. We know that on the one hand the amount of zinc consumed in a battery in any time is proportional to the time and to strength of the current; on the other hand, if we do not vary the E. M. F., the heat produced is also proportional to the same two factors. It follows that the generated heat must be proportional to the quantity of zinc consumed. Favre, who more fully investigated the subject, found that 33 kilogrammes of zinc used in an element gave 18·160 heat units, or calories. (A heat unit, or calorie, is that quantity of heat which is required to raise 1 kilogramme of water from 0° to 1° C.) Now let us calculate what quantity of heat will be strictly equivalent to the energy of chemical separation liberated, or of chemical combination absorbed. For the quantity of heat when zinc dissolves in sulphuric acid (that is, in the formation of zinc sulphate) the following result is obtained by using the tables of Favre for the number of heat units evolved or absorbed in the combinations that take place in the case before us.

By the conversion of zinc to zinc oxide	42·451	calories.
By the formation and solution of zinc sulphate	10·292	,,
Total ...	52·743	,,

When zinc dissolves in H_2SO_4, 1 gramme of H is liberated as well. This takes up 34·462 calories of heat, the equivalent of the energy of chemical separation. This amount has to be deducted from the above; we then obtain as the heat units generated by the chemical process 52·743 − 34·462 = 18·281 calories. Taking into consideration unavoidable sources of error, this result agrees very nearly with the result found by Favre.

The heat units generated by the chemical action in constant batteries must be to each other as their electromotive forces. This can be proved to be so by coupling a Grove's element with a Daniell's. By the conversion of an equivalent of zinc, 52·743 heat units are generated. In Daniell's element, for every equivalent of dissolved zinc an equivalent of copper is separated; for this separation or reduction of copper from copper sulphate 29·645 units of heat are wanted. We have, then, in a Daniell's element 52·743 - 29·645 = 23·098 heat units. In Grove's element, corresponding to the amount of dissolved zinc sulphate, a quantity of nitric acid is reduced to nitric oxide; for this reduction 6·900 calories are needed, and we obtain for the total quantity of heat in a Grove cell 52·743 - 6,900 = 45·843 heat units. The proportion of the two would be $\frac{45·843}{23·098}$, which gives us the figures 1·9, which is the proportion

of their E. M. F's. The total amount of heat, then, generated in an element is proportional to the amount of zinc used, and is, according to Helmholtz, equal to that quantity of heat which becomes free by the chemical action in the element. If the element is short-circuited, the two electricities neutralise each other in the proportion in which they are generated, without doing any other work than producing heat in the conductors. It is impossible to destroy energy, and all we can do is to change it into some other form of energy. Here, in our case, the galvanic current shows no other result of energy of current except that of heat. This explains why, according to Joule's law, electricity must be converted into heat.

By generating heat in the different parts of a circuit, the temperature of these parts must be increased; upon what does the temperature of the parts in the circuit depend? The temperature of any body depends upon the difference between the quantity of heat it generates within itself, or obtains from without, and the quantity of heat it loses to surrounding bodies. The temperature of a body becomes constant as soon as the heat received or generated is equal to that radiated. Joule's law tells us upon what the quantity of the heat generated in any wire depends, and we know from experiments on radiation that the loss of heat depends upon the nature and extent of the surface of the body, and the difference of temperature between the body and its surroundings. The temperature of a wire depending upon the difference of the heat generated and the heat radiated will be the higher the greater the current and its own resistance, and the smaller its surface and power of radiation. When these conditions are fulfilled the wire will pass to a red heat, then to a white heat, and will finally fuse. A thin wire, therefore, is easily made red-hot: its resistance on the one hand is very high; on the other hand its surface for radiating heat is only small.

The heating of wires by the galvanic current may be shown by connecting the wires of a battery (short thick copper wires) with a thin platinum or iron wire. The resistance in the battery is reduced as much as possible by selecting elements with large plates, or if large plates are not handy, by arranging small plates, not in series, but in parallel order. With these conditions it is possible to cause most of the heat generated by the electricity to show itself in the platinum wire.

The total quantity of heat generated in the circuit is proportional to the amount of zinc consumed in the battery; the current, as we have seen, is the same in all parts of the circuit. It follows that the quantities of heat generated in different parts of the circuit depend only upon the resistance of these parts. If, therefore, we wish to produce heat only in one of these parts, that particular part must have a great resistance, whilst the resistance of all the other parts of the circuit must be reduced as much as possible. It has been mentioned that different bodies possess different specific resistances: hence, in the heating of bodies by means of the galvanic current, different temperatures must be reached when bodies having the same dimensions, but consisting of different

materials, are taken. That this really is the case may be shown by arranging platinum and silver wire as in Fig. 135. It will be found that the platinum links begin to glow, whilst the silver links show no sign of heat. The laws regarding incandescence of wires, etc., we shall discuss in the second portion of this work. It has been mentioned that the surrounding medium affects the heating of a wire; for instance, Grove heated a platinum wire in air, and then

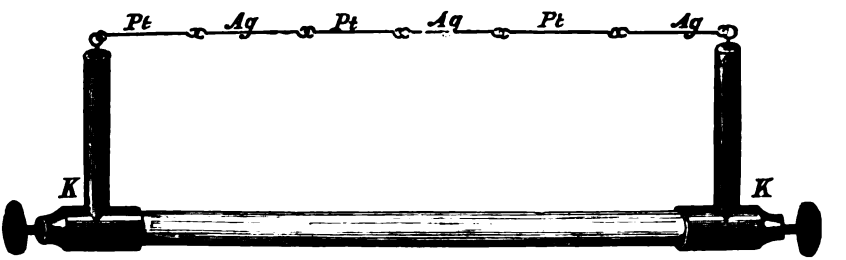


Fig. 135.—Heating Effect of Current on Platinum and Silver.

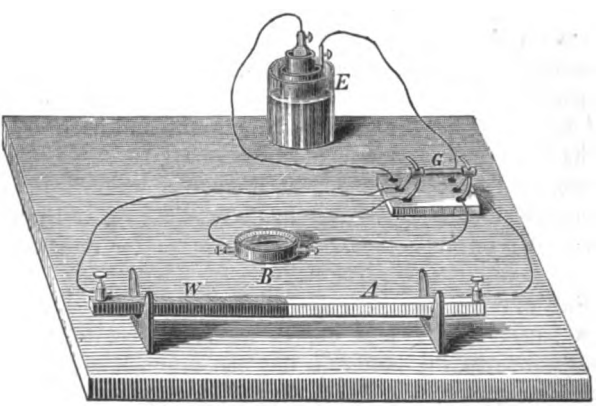


Fig. 136.—Peltier's Bar.

introduced the red-hot wire into a vessel filled with hydrogen; the wire lost its red heat immediately.

The Peltier Effect at a Junction of Metals.—Peltier found that when a rod, consisting half of bismuth, half of antimony, is heated at the junction of the metals, and the two ends are connected by a wire, a current flows through the whole system: positive electricity flows across the junction from bismuth to antimony; when the junction is cooled the current flows in the opposite direction. If, however, a current is sent through such a rod in the direction from bismuth to antimony, the junction becomes cooled; when the current flows from antimony to bismuth the junction is heated. If the heating of a junction produces a current in one direction, to send a current in that

direction will cause a cooling of the junction. This phenomenon not only takes place at the junction of bismuth and antimony, but with all combinations of metals which are thermo-electrically effected. To study these phenomena the experiment may be arranged as shown in Fig. 136. The free ends of the bismuth-antimony rod W A are connected by means of wires with the middle mercury cups of Pohl's gyrotrope G. The wires dipping into the first mercury cups are connected with a galvanometer, and the remaining wires with the element E. If now we allow the current to pass from bismuth to antimony, the junction will be cooled. This causes a thermo-electrical difference in the rod W A, which is made manifest by the deflection of the needle when the gyrotrope is reversed so as to cut out the element and bring in the galvanometer. In the same manner the heating of the junction may be shown by sending the current in the opposite direction, that is, from antimony to bismuth. Another arrangement is shown in Fig. 137 (Peltier's cross). Bars of antimony and bismuth A and W are arranged in the form of a cross, and soldered at the place of contact. If a current from a Daniell's cell is sent in the direction D *b e a* D, the junction *e* will be cooled; if, then, this circuit be interrupted, a thermo-current will flow through the galvanometer circuit *d e c* B. The heating and cooling of a junction, when a galvanic current is sent through it, may be shown directly by placing the junction of a bismuth-antimony bar in the globe of Riess's air thermometer already described. Cooling by means of the galvanic current was shown by Lenz very effectively in the following manner: he soldered a bismuth-antimony rod, as shown in Fig. 136, and bored a small hole at the junction. The bar was placed in melting snow, and the hole filled with water. When the rod was at a temperature of 0°, Lenz passed a current in the direction from bismuth to antimony, and five minutes afterwards the water in the hole was frozen, and reduced to a temperature of $-4{\cdot}4°$ C.

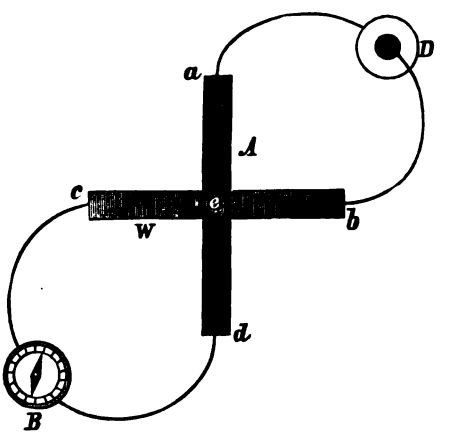


Fig. 137.—Peltier's Cross.

In order to complete the law for the amount of heat developed in any part of the circuit, it is evident therefore that we must take account of the Peltier effects at the junction in this part. If the heating of the junction produces an E. M. F. of P units, then the mechanical equivalent of the heat produced in t seconds in this part of the circuit will be $C^2 Rt + P Ct$.

Lighting Effects of the Galvanic Current.—When the circuit of a galvanic battery is interrupted at any place, a spark will be seen similar to the one obtained from a Leyden jar. Galvanic sparks are produced when one wire of a

battery is connected with a file, and the other wire is rubbed over it. The sparks are obtained most easily with metals that evaporate or burn at the place of interruption. The latter happens when the iron file of the one pole is stroked with the other pole; the former takes place (evaporation) when one pole dips into mercury and the other is taken out from it. The colour of the spark depends upon the metals which happen to be at the place of interruption. The galvanic spark, however, is not observed when the circuit is made.* This circumstance shows that its origin is not due to the same cause as the spark of a Leyden jar. The so-called galvanic spark is more a kind of glow than a spark.

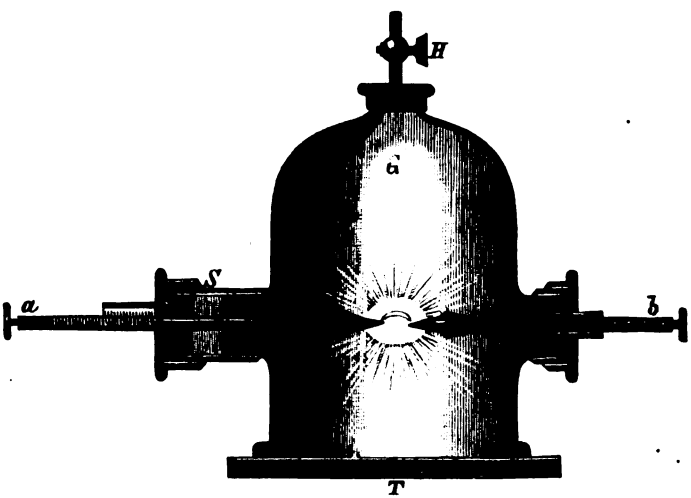


Fig. 138.—Arc Micrometer.

We know that a wire, through which a current flows, glows most intensely when its cross section is smaller. Such a diminution of section takes place always when the circuit of a galvanic battery is interrupted; the cross section is diminished more and more as fewer and fewer parts touch each other, and finally, the few parts still in contact begin to glow, fuse, burn, or evaporate; the burning or evaporating particles then form the galvanic spark. In this way we are able to explain why no spark appears either when the circuit is closed or when the terminals are separated by any appreciable distance.

The Voltaic Arc.—In addition to this glow where the wires touch, galvanic batteries are able to give sparks like those from a Leyden jar when a great number of elements are combined. Crosse obtained sparks at the place of interruption in a battery of 1,626 copper-zinc elements. Gassiot saw for days sparks pass from a battery of 3,520 elements, the distance between the poles

* Jacobi brought the poles of a twelve-cell zinc platinum battery, by means of a micrometrical screw, to a distance of 0·00127 millimetre without obtaining a spark.

being 0·25 millimetre. Sparks can be made to pass continually without using such large batteries, by bringing the poles of a powerful battery together, and then leaving them at a short distance from each other; we obtain then what is known under the name of the voltaic arc. The first who observed this phenomenon was probably Davy (1802). Davy attached to the poles of a battery of 2,000 elements carbon rods, which he first allowed to touch each other, then separated them. When the distance of the carbons from each other was 10 centimetres he obtained a splendid arc of light. A very good effect is obtained by using 20 to 30 Grove's or Bunsen's elements. The length of the arc, that is, the distance of the carbon points from each other, may be ascertained by means of the apparatus devised by Wiedemann, shown in Fig. 138. G is a bell-jar, which fits the air-pump plate T air-tight, and has at the top a stop-cock H, by means of which the outer air can be cut off. The rods *a* and *b* carry the carbon points. The rod *a* goes through the stuffing-box S, and has a scale to indicate the distance of the points from each other. When the air is exhausted in the bell-jar the points may be removed farther from each other without destroying the arc than when the jar is filled with ordinary air under ordinary pressure. Davy exhausted the air to 6 millimetres pressure, and moved the carbon points from 11 centimetres to 18 centimetres distance from each other. Deprez found that with a vertical arrangement of the carbons the arc becomes larger when the positive pole is above the negative pole. The arc is greatly influenced by the material used for points, and it has been observed that the more volatile the material of which the electrodes are made, the easier the arc is obtained. It is difficult to obtain an arc with platinum points; easier with points consisting of metals such as zinc, etc.; easiest with carbon points, especially when saturated with some salt solution. Casselmann obtained, with a 44 Bunsen battery, an arc 4·5 millimetres long when he used carbon points, but an arc of double that length when he soaked his carbons in a solution of potassium.

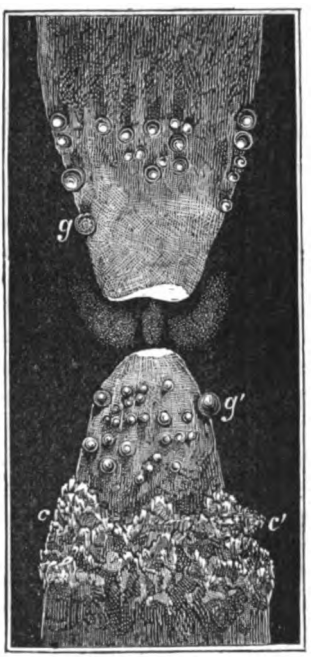


Fig. 139.—Carbon Points of Arc Light.

Fig. 139 represents the carbon points a short time after production of the light. The positive electrode forms a cavity giving out the total quantity of light in directions corresponding to the cavity, and therefore embraced within an angle of about 65°, whilst the negative electrode remains almost pointed, and therefore sends its rays of light in *all* directions. On both electrodes little globules *g* are often noticed, which are metallic impurities, and do not appear

when pure carbon points are used. As only the positive electrode wastes away, attempts have been made to make it of harder substance than the negative electrode; but it has been found that the arc then becomes as difficult to light as if both electrodes were made of the harder material. Breda has proved, by making use of two different metals, as well as by weighing, that no particles are carried away from the negative electrode. The voltaic arc, therefore, is a mass of incandescent particles of the electrodes, moving chiefly in the direction from the positive electrode to the negative. The intensity of the arc light, and the evaporation of even the hardest metals by means of it, prove its temperature to be a very high one; perhaps the highest we are able to produce. Not only metals like iron, zinc, copper, etc., burn in it with great splendour, but even carbon is partly volatilised. Using carbon points in a vacuum, Deprez found the carbon vapour condensed in the form of small crystals on the inside of the bell-jar. Little pieces of carbon were welded together by the intense heat of the arc.

If we suddenly stop the current, we find the positive electrode white-hot, whilst the negative is hardly red-hot. If we produce an arc between mercury and a wire, and when the wire is the positive pole, we find that the wire will be white-hot a good distance up; if, on the other hand, the mercury be the positive pole, the wire remains dark, and the mercury becomes heated and evaporates. These experiments show, then, that different quantities of heat are generated at different poles; the positive electrode showing a considerably higher temperature than the negative electrode. Rosetti, by using a Bunsen battery of 160 elements and a Duboscq's lamp, found the temperature between the two carbon points from 25,000° to 39,000° C., the positive electrode had about 2,400° to 3,900°, and the negative from 2,138° to 2,530° C. The temperature obtained with ten Bunsen elements and a lamp by Reynier was 2,406° to 2,734° C. The statement, that one of the advantages of the electric light lies in keeping the space where it is employed comparatively cool, is in no way contradicted by the above figures of temperature; for the heat-giving surface of the electric light, compared with other sources of light, is so small that the total amount of heat generated by an electric light would be far less than that from other sources. Siemens found that an electric light of 4,000 candles produces 142·5 heat units per minute. To obtain the same amount of light by means of gas, we should require 200 Argand burners, which produce 15,000 heat units. The electric light, therefore, produces about 1 per cent. of the heat which would be produced by gas lights *of the same intensity*.

For the comparison of the intensities of the electric light and sun light rays of each source of light were first collected by means of convex lenses, and then allowed to act upon a Daguerreotype plate. The times were compared which the light of each source required to produce the same effect. The intensities of the lights were then taken inversely proportional to the times. This is only a comparison of the effective chemical rays, the electric light being relatively richer in these than sun light; the proportions as given above are not correct, therefore. The relative wealth of the electric light in effective

chemical rays, to which especially the violet rays are connected, was proved by spectrum analysis. If different substances in the form of vapour be made to glow, and then the rays of light which the vapours send out be examined, it will be found that each substance has its characteristic spectrum. When the electric light is examined in this manner, the characteristic spectrum for the substance chemically composing the electrodes is obtained. After the electrodes have touched each other, and are then separated, a spark passes. This spark is produced at first in the way described. By removing the surfaces that are in contact from each other we lessen the cross section of the circuit more and more, until the cross section becomes so small that the particles still touching each other begin to glow, and are carried away by the current. When now the two electrodes are separated a very little distance from each other, the glowing particles form a bridge between the two electrodes, and the current can pass through this stream as a conductor, although a bad one. The tearing off of the particles once commenced by the spark continues, and will be maintained the easier the more easily the electrode particles can be torn off; in other words, the electrodes may be separated the farther from each other the more readily the material of the electrode volatilises. If, however, the distance is increased beyond a certain limit the particles are no longer capable of flying from the one electrode to the other, and the current is interrupted; the arc dies out, and can only be lighted again by bringing the two points together. Le Roux found that the current might be interrupted for not more than one-twenty-fifth of a second without the light dying out. We may conclude from this that the current does not cease when the arc of light is formed. The resistance of the arc seems to be only very slight; in fact, the current must be conducted by it. The measures obtained by different observers for the resistance in the arc vary very much, but the cause of the discrepancy will be found in the nature and behaviour of the arc itself, which we shall explain farther on. Siemens takes the resistance to be 1 (Siemens' unit); Schellen, from 30 to 40; Hagenbach, 4·75; Uppenborn found for the ordinary arc light 2 and incandescent light 4 Siemens' units; Edlund, varying the length of the voltaic arc, found the following values:

Length of arc	2	millimetres	a resistance	7·8
,,	1·6	,,	,,	7·6
,,	1·2	,,	,,	7·3
,,	0·8	,,	,,	7·1
,,	0·4	,,	,,	6·9.

These experiments show that the resistance does not entirely depend upon the length of the arc; there must be another agent which helps to weaken the current. This agent was found to be an E. M. F. which is generated in the arc, and opposes the galvanic current that produces the arc. This opposing force is measured as resistance, and is one of the chief causes that such different results are obtained.

Edlund proved directly the presence of an opposing electromotive force. The current that produced the arc was suddenly interrupted (it has been stated that the arc does not die out immediately after the current ceases), and at that moment a galvanometer was connected with the two carbons. The deflections of the needle indicate the opposing current.

Chemical Effects of the Galvanic Current.—We have frequently had occasion to mention certain chemical effects of electricity, namely, the decomposition of gaseous compounds into simple gases, or the production of gaseous compounds from simple gases by means of the current; as, for instance, the separation of iodine from potassium iodide, or precipitation of copper from cupric sulphate. These changes are more distinctly and powerfully brought about by galvanic-batteries and other electrical machines, which we shall have occasion to describe later on. Carlisle (1800) dipped a copper wire which was connected with one of the poles of a voltaic pile into a drop of water, which happened to be on the plate connected with the other pole; gas bubbles appeared, and the drop of water became smaller and smaller This experiment was repeated in a somewhat different manner, the brass wires from a pile being brought under a tube filled with water, and closed at the top. Gas bubbles were produced by the wire in connection with the negative pole of the pile, and the water was observed to gradually diminish. At the positive wire, on the contrary, no gas came off, but the metal lost its metallic lustre, became dark, and finally crumbled away. The gas which had collected in the tube proved to be H; while on examining the black mass it was found that the constituents of brass, viz. copper and zinc, had become oxidised.

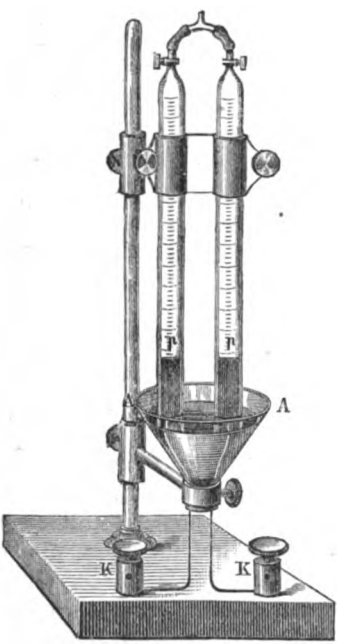


Fig. 140.—Eudiometer.

In order to obtain O in a gaseous form, a metal must be taken, such as platinum, that does not oxidise. The gases can then be collected in different tubes, the hydrogen tube receiving twice as much gas as the oxygen tube; since water consists of two vols. of H and one vol. of O, it follows that the galvanic current decomposes water into its constituents. H is always evolved at the negative pole of the battery, and O at the positive pole. Several forms of apparatus for the decomposition of water have been devised; one of which is represented in Fig. 140. Water here is sucked at A into the tubes *p p*; as chemically pure water has so great a resistance as almost to force us to consider

it a non-conductor, it is generally acidulated with sulphuric acid, H_2SO_4. The smallest amount of acid diminishes the resistance considerably.

Faraday's Nomenclature.—Faraday called the compound to be decomposed an *electrolyte*, and the process *electrolysis*. The poles or plates in contact with the water he called electrodes. At the positive electrode, or, as Faraday called it, the anode, H is given off; at the negative electrode, or kathode, O is evolved. The anode is the wire through which the positive current enters the fluid; kathode the wire by which the current leaves the fluid. Hence in electrolysis, H, or the metallic element that takes its place, is driven with the current through the electrolytic cell. The products of decomposition are called *ions;* the ion appearing at the kathode is called the positive ion, or *kathion*, and the ion at the anode the negative ion, or *anion*.

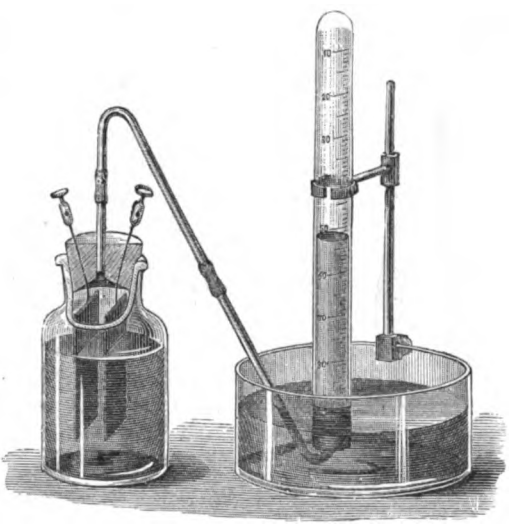


Fig. 141.—The Voltameter.

Results of the Electrolysis of Water.—Two Daniell's elements at least must be used for the decomposition of water; one element cannot effect it, for the backward E. M. F. produced by the free gases is greater than that of a single Daniell's cell. If these precautions are taken, decomposition of water is easily brought about. Oxygen coming off at the anode, forms, therefore, the negative ion, or kathion, and hydrogen forms the anion. A slight inaccuracy appears after decomposition, that is, we do not get exactly two vols. of H to one vol. of oxygen. The reason is that as it is more soluble in water than hydrogen, more O will be dissolved than H. If the water is strongly acidulated with H_2SO_4, the oxygen undergoes a further modification, forming ozone. Ozone is oxygen in a condensed condition. It is produced in comparatively large quantities by the action of electrical discharges upon oxygen. The *silent* discharge is far more effective in bringing about this transformation than the spark discharge. According to Meivinger and Schonbein, the volume of O may further be reduced, under certain conditions, and another product formed during decomposition, viz. H_2O_2, hydrogen peroxide. H_2O_2 diluted with water is used for cleaning pictures and taking away the colour of hair. Water containing a great percentage of H_2SO_4 may lose as much as 0·6 per cent. of O during the formation of this compound. Decomposition of water

has already been referred to as a means of measuring the strength of a current. The apparatus by means of which this may be done is called a voltameter, and is shown in Fig. 141. Water is decomposed in the bottle and collected in the graduated tube; only one tube is used here, as we only require to know the volume of the two gases.

Examples of Electrolysis.—Not only can water be decomposed, but so can any fluid that will at all conduct a current. By electrolysis, Davy, as has already been mentioned, first obtained potassium and sodium from their oxides. He heated potassium oxide in a platinum spoon till it melted, used the platinum spoon as anode, and put into the molten potassium oxide another platinum wire, which represented the kathode. At the kathode, metallic potassium was separated, and of course at once took fire, and at the anode oxygen was given off. Davy also obtained potassium by bringing slightly moistened potassium oxide between the electrodes.

Fig. 142. — Bunsen's Electrodes.

Seebeck obtained potassium in the following manner: A piece of solid potassium oxide, in which a hole is made, is laid upon a platinum plate serving as anode. The hole in the potassium oxide is filled with mercury, and into it a platinum wire is brought, to serve as kathode. As soon as the circuit is completed the separation commences at the kathode. Metallic potassium forms with the mercury a kind of amalgam, from which it is obtained pure after the mercury is driven off by distillation. Sodium, calcium, barium, and strontium may be obtained from their compounds in a similar manner. The oxides of the heavier metals can be decomposed by the galvanic current only when they can be made to conduct electricity.

Faraday decomposed protoxide of lead by first melting it and then passing a current through it. Lead separated out at the kathode, and oxygen was given off at the anode. The halogenous compounds (salts of chlorine, bromine, and iodine) are similarly decomposed by the electrical current; these, however, act on metals, and it is therefore necessary to make the anode at least of carbon. The simplest way to obtain chlorine, bromine, and iodine from their compounds is to have a carbon crucible, which represents the anode; and an iron wire, which serves as kathode. The wire is removed from time to time to scrape off the separated metal.

To obtain magnesium, Bunsen used a porcelain crucible, which was separated into two portions by a partition which did not quite reach to the bottom. The crucible had a lid with two holes in the centre of each partition to hold the electrodes, which consisted of pure carbon. The form given to the electrodes is shown in Fig. 142. To prevent the magnesium rising to the surface, where it would burn away (as it is lighter than chloride of magnesium), incisions are made to hold it and allow it to collect. For the electrolysis 10 or 12 Bunsen's cells arranged in series are used.

It is not necessary that the binary compounds, consisting of two elements,

which we have had under consideration, should be in the solid state; their solutions will do as well. Chlorides of tin, lead, and manganese can be decomposed when in solution, but the solutions of compounds of chlorine, bromine, and iodine have to be very concentrated.

Secondary Reactions in Electrolysis.—From metallic hydroxides the metal can be separated with due precautions. For instance, as we have already stated, we may obtain potassium by pouring potash into which a platinum wire is introduced as anode over some mercury, which serves as kathode. The potassium separating out at the kathode combines at once with the mercury to form an amalgam of potassium, from which the pure potassium may be obtained by distillation. If both the electrodes were of platinum, the electrolysis would not give metallic potassium; for here, although O appears at the anode and potassium at the kathode, potassium comes in contact with water, which it decomposes at once, and forms potassium oxide soluble in water; the H set free escapes. Here, then, we have H at the kathode and O at the anode; the same result as is obtained by decomposing water. This result is, however, not obtained through electrolysis directly, but is a secondary reaction. Frequently the bodies separated by means of electrolysis act upon each other in this way, and thus disguise the real process. In order to prevent this, many forms of electrolytic cell have been devised by experimenters. We shall describe here two: Daniell used the apparatus shown in Fig. 143; upon the U-shaped glass tube K, the two cylindrical glass vessels *a d* and *e h* are fitted air- and water-tight. The tubes fitted at the top serve to carry off gases that may be produced. The two electrodes consist of platinum plates *o* and *p*, from which wires lead to the mercury cups *t* and *s*, into which the wires of the battery dip. The liquid to be decomposed is placed in the U-shaped tube; the open ends are covered with bladders, and the glass cylinders filled with water and replaced. The products separating out at the anode and kathode come, therefore, from the liquid in the U-shaped tube. The separation is, however, not complete, for a mixing of the gases due to endosmosis takes place, as it does when two different solutions are separated from each other by an animal membrane, such as a bladder. A similar result comes from a different

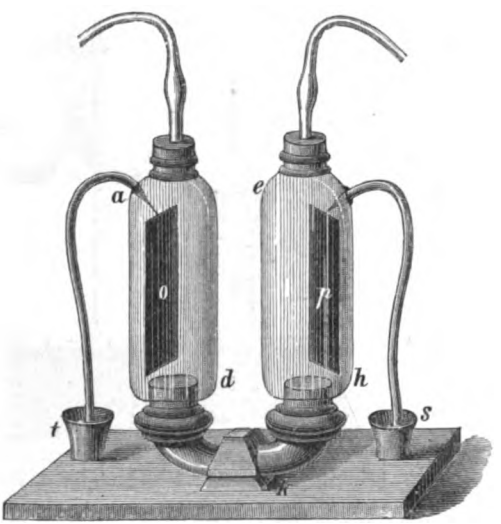


Fig. 143.—Daniell's Electrolytic Apparatus.

cause, which will be explained later on, namely, the action of the galvanic current in producing what has been called electrical endosmosis.

To avoid these sources of inaccuracy Wiedemann devised the apparatus shown in Fig. 144: a and a_1 are two glass cylinders covered with glass plates b and b_1. Each glass plate has two openings: through one the wires l and l_1 are put, and through the second the tubes d and d_1 enter the glass cylinders; f is a piece of indiarubber tubing which connects the tubes d and d_1 with the tube g having a stop-cock: g is held in position by the iron stand h. The

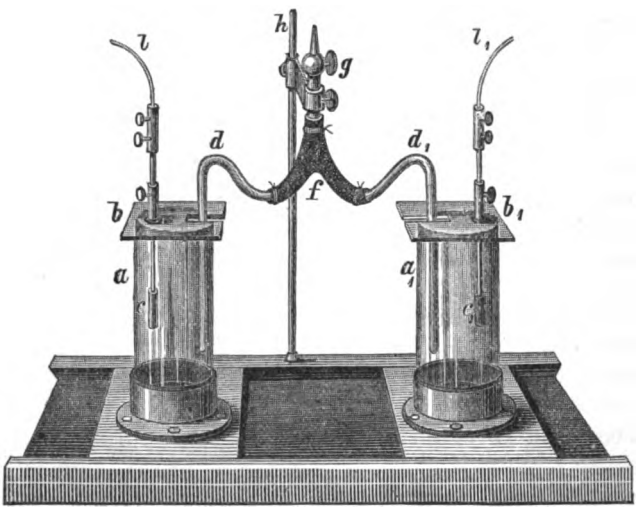


Fig. 144.—Wiedemann's Apparatus.

liquid to be decomposed is poured into the two glass cylinders, and then sucked into the tubes d and d_1, until it reaches g, when the stop-cock is closed.

Contact is now made between the liquids in a and a_1. The current now decomposes the liquid into its products separately. After the experiment is finished, g is opened, which causes the liquid to flow back again, and the ions may be examined separately.

In the decomposition of sulphates and nitrates the pure metal separates out at the kathode, while O is given off at the anode. Let us consider, for example, the behaviour of copper sulphate during decomposition. Copper sulphate may be considered as sulphuric acid, in which the hydrogen is replaced by copper. Sulphuric acid consists of:

2 hydrogen + 4 oxygen + 1 sulphur.

And copper sulphate consists of:

1 copper + 4 oxygen + 1 sulphur.

By electrolysis from copper sulphate are separated :

at the kathode	at the anode
1 copper	1 sulphur + 4 oxygen.

1 sulphur + 4 oxygen combine with water in the following manner :

1 sulphur + 4 oxygen combine with 2 hydrogen + 1 oxygen

$$\text{or } SO_4 + H_2O = H_2SO_4 + O.$$

We have therefore :

at the kathode	at the anode
1 copper	1 sulphuric acid and 1 oxygen.

If now we decompose potassium sulphate we obtain an apparently different result. In the solution at the anode we find H_2SO_4, and at the same time O is generated. In the solution at the kathode potash has been formed, whilst H is generated ; this, however, is the secondary process, already described, as we shall see :

Potassium sulphate consists of K_2SO_4, that is to say of
2 potassium + 1 sulphur + 4 oxygen.

Potassium separates out at the kathode, combines with water, and is decomposed together with it in the following manner

$2K$ with H_2O gives K_2O and $2H$; that is,

potassium oxide and H which escapes at the kathode.

1 sulphur + 4 oxygen combine with water to form sulphuric acid as before.

$$H_2O + SO_4 = H_2SO_4 + O$$

The oxygen escapes at the anode.

Whatever the substances we expose to the action of the galvanic current, decomposition takes place proportional to the strength of the current, but we have yet to ascertain the law relating to the proportion of the different bodies when decomposed by the same current. Faraday used for this purpose concentrated hydrogen acids, in which only the acids and not the water were decomposed. HCl gave chlorine at the anode (only in small portions, of course, for it is very soluble in water), and H at the kathode. By inserting a voltameter in the circuit, he found that the same volume of hydrogen resulted from the decomposition of water in the voltameter and from HCl in the electrolytic cell. The same fact has been proved by Daniell, Buff, and others. A solution of copper sulphate, for instance, is decomposed into copper and sulphuric acid. Now the constituents of copper sulphate, with their atomic weights, are as follows :

1 copper	63
1 sulphur	32
4 oxygen (16)	64
copper sulphate	159

Water consists of :

2 hydrogen	2
1 oxygen	16
water	18

Now it is found by experiment that by the decomposition of water and copper sulphate, for every gramme of oxyhydrogen gas 3·522 grammes of copper are separated out in the same time. This is in accordance with Faraday's law, for the proportion is that of their atomic weights.

$$\frac{1}{3{\cdot}522} = \frac{18}{63}$$

The laws laid down by Faraday may be thus stated :

Laws of Electrolysis.—(1) The amount of chemical action is equal at all points of a circuit at which it occurs.

(2) The amount of an element (or ion) liberated at an electrode for a given time is proportional to the strength of the current.

(3) The amount by weight of an element (or ion) liberated at an electrode in one second is equal to the strength of the current multiplied by the "chemical equivalent" of the element (or ion), and by the number ·0000105, which is the weight of hydrogen set free in a second by a current of one ampere.

The following equation embodies the rule for finding the weight of any given element disengaged from an electrolytic solution during a known time by a current whose strength is known. Let C be the strength of the current (reckoned in amperes), t the time (in seconds), z the chemical eqivalent, and w the weight (in grammes) of the element liberated, and let h grammes of H be set free by a unit current per second, then

$$w = zCth,$$

or,

$$\text{Strength of current in amperes} = \frac{\text{wt. in gms. of H liberated per sec.}}{.0000105}$$

If, instead of hydrogen, another element be liberated, then the denominator must be multiplied by the chemical equivalent of that element thus :

$$\text{Strength of current in amperes} = \frac{\text{weight of silver liberated per sec.}}{\cdot0000105 \times 108}$$

The same law applies to *each cell* of the battery for which

$$\text{Strength of current in amperes} = \frac{\text{weight of zinc dissolved per sec.}}{\cdot0000105 \times 32{\cdot}5}$$

By the help of this law the quantity of any metal which a constant current can separate in a given time from a solution of the salt is easily calculated. All we require to know is the composition of the salt, the chemical equivalents or atomic weights of the components, and the strength of the current.

By applying this law to the definition of unit current we may add to the definition of an ampere the following: A current of one ampere is that which will decompose 0·00009324 gramme, or 0·001439 grain of dilute sulphuric acid per second. The volume of mixed gas (oxygen and hydrogen) that is produced per second by this decomposition equals in cubic centimetres

$$\frac{0{\cdot}1738 \times 76\,(273 \times \text{C.}^\circ)}{h \times 273},$$

where C.° is the temperature of the mixed gas in degrees centigrade, and h the pressure in centimetres of mercury.

The same current is found to deposit 0·0003295 gramme, or 0·005084 grain, of copper per second on one of the plates of a copper voltameter, and 0·0003390 gramme, or 0·005232 grain, of zinc per second on one of the plates of a zinc voltameter.

The Counter E. M. F. in Electrolysis.—Let us once more return to the example of the decomposition of copper sulphate by a current, and examine more minutely what takes place. The two electrodes, consisting of two equal plates, when placed alone in the liquid, will produce no effect whatever. If, however, a current is sent through them, the liquid will be decomposed into its constituents in such a manner that the copper separates out at the negative electrode, and the sulphuric acid at the positive electrode; during the process copper covers the kathode, whilst sulphuric acid leaves the anode unaltered. Now two different metals dip in the copper sulphate solution (the copper plate and the bright platinum plate), but contact of different metals with a liquid, as we have seen, causes an electromotive force; a current, therefore, is generated, the direction of which is determined by the nature of the ions. This phenomenon is what we have called polarisation, or it is said the electrodes are polarised. Experiments show the direction of the polarisation current to be opposite to the current originally sent through the liquid; the polarisation current, therefore, is an opposition current, and must weaken the original current. Polarisation not only takes place when at one of the electrodes a metal separates out, but also by decomposition of ordinary water; here H is given off at the kathode and O at the anode; the two gases coat the platinum electrodes with a film which gives them an E. M. F. Under otherwise similar conditions polarisation will be the stronger the more completely the plates are covered with the gaseous film. From the beginning of the electrolysis it will increase until the electrodes are perfectly coated, and then it will remain of constant strength, as further evolution of gas will no longer have any effect. If the E. M. F. of the original current is weaker than that of the polarisation current, the latter will not be able to attain its maximum strength, because a

current would be generated opposite to the original current, which would arrest further polarisation. Ohm's law for galvanic currents gives us the equation

$$\text{Current} = \frac{\text{E. M. F.}}{\text{total resistance}}.$$

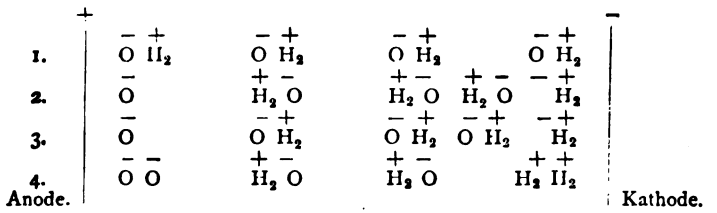
This proposition, however, only holds good as long as no fluids are inserted in the circuit; if fluids are part of the circuit, we have the following proposition:

$$\text{Current} = \frac{\text{E. M. F. of the element} - \text{E. M. F. of the polarisation current}}{\text{total resistance}}$$

The existence of a polarisation current may be shown by inserting a commutator, voltameter, and galvanometer in the circuit of a battery. The commutator is first so arranged that the current of the battery only passes through the galvanometer and voltameter, which causes polarisation of the electrodes of the voltameter. The commutator is now brought into the second position, which removes the battery from the circuit of the galvanometer and voltameter. The deflection of the needle again indicates a current (the polarisation current), which flows in the opposite direction to the battery current. Ritter (1803) was probably the first who observed a polarisation current. The phenomenon has been very fully investigated of late, and has led to the construction of secondary elements, which have received the not very appropriate name of accumulators. Into such an element the current of a battery is introduced, polarisation being thereby produced. If now the circuit of the charged element be closed, the polarisation current will circulate through the circuit of the element in the opposite direction to the battery current. H will be given off where O was evolved, and *vice versâ*. In this manner that which caused the polarisation current will be gradually diminished, and with it the polarisation current itself. It becomes nought when through the decomposing effect of the polarisation current the hydrogen at the one electrode and the oxygen at the other electrode are used up. The secondary element is then discharged; that is, it is in its original condition. Secondary elements, like galvanic elements, may be connected with each other to form batteries. Their forms and combinations will be discussed in the second part of this work.

Theory of Electrolysis.—Explanations regarding what takes place during electrolysis have been frequently attempted, but beyond more or less probable hypotheses, nothing has been proved. This is not surprising when we consider that the nature of electricity itself is unknown to us. Grotthuss (1805) gave the following explanation of electrolysis: the constituents of the electrolyte are oppositely electrified. For instance: in water, oxygen is negatively, hydrogen positively, electrified. In their natural condition the molecules of water are supposed to assume all kinds of positions. Into these the electrodes of a battery are introduced, and a current is sent through them. As soon as the electricities at the electrodes have obtained a certain density, their forces of

attraction and repulsion cause all the positive hydrogen atoms to turn towards the negative electrode, and all the negative oxygen atoms towards the positive electrode. The positive electrode attracts all negatively electrified oxygen particles, and repels all positively electrified hydrogen particles. The negative electrode attracts the positively electrified hydrogen and repels the negatively electrified oxygen. Both electrodes tend therefore to separate the O from the H, and this will be effected at the electrodes first, because there the forces are strongest. The O of the molecule nearest the positive electrode is attracted by the anode, and held fast there; the H, however, is repelled, and forced towards the negative electrode. This atom of H combines with the O of the nearest molecule of water from which the H atom is forced out. The H forced from the second row of water molecules reaches the third row, and combines again with the O to form water. This process is repeated through all the molecules which are between the two electrodes, until the H finds no longer any O in the row of molecules nearest the kathode with which to combine. The result of the whole process is that O is given off at the positive electrode and H at the negative electrode, whilst between the two electrodes the water remains undecomposed. After this process is finished the water molecules have their hydrogen atoms directed towards the positive electrode, and their oxygen atoms directed towards the negative electrode, assuming, therefore, a position opposite to that produced by the forces of attraction and repulsion of the electrodes. Hence these forces will cause the water molecules again to alter their position, and the process described above is repeated. The following table, in which H stands for hydrogen and O for oxygen, illustrates the steps of the process:



After the first step the molecules of water are directed so that the H points to the copper and O to the zinc. After the second step oxygen is evolved at the anode, hydrogen at the kathode, and the remaining atoms of H and O unite to form new molecules of water. After the third step the molecules of water are again directed; and after the fourth step they are again decomposed.

Although this explanation accounts for the fact that only at the electrodes are the ions separated, and also for the proportion which anion and kathion bear to each other, it leaves unexplained other features of the phenomenon. For these and other reasons the hypothesis of Clausius seems to be preferable. Clausius, too, assumes an electrified condition of the molecules of each electrode, but he neither attributes to the galvanic current the force of direction

nor power of decomposing. He points out that both the molecules of fluids and also their atoms are in continual motion. The atoms in molecules of fluids are held together but by a moderate force, and the molecules themselves constantly undergo changes both of synthesis and analysis. The galvanic current merely effects a regulated motion of the atoms; the positive ions are attracted by the negative electrode, and the negative ions by the positive electrode, and by this means are separated out from the liquid.

Minor Effects of Current.—Before we close this chapter we have to point out some effects of the galvanic current of minor importance. If a current is passed through a small vertical tube containing some fluid, and having two platinum wires fused into the glass, the liquid is observed slightly to rise when the current is passed upwards through the tube. The height through which the liquid rises is proportional to the current and the cross section of the tube. Similarly, Reinold and Rücker found that an upward current passed through a perpendicular soap-film enormously retarded the thinning of the film, which was almost arrested. A somewhat similar phenomenon, called electrical endosmosis, takes place when during electrolysis porous partitions are used as in Daniell's apparatus. The liquid moves then from the anode through the porous partition to the kathode. This phenomenon is analogous to the rising of liquid in the tube, for the porous partition resembles a series of small capillary tubes.

In addition to these effects, the galvanic current produces mechanical effects also. Copper wires, which have been in use for some time, become brittle. Dufour passed a current from a Bunsen cell through a copper wire for nineteen days, and found that the wire broke when 5·34 kilogrammes were suspended from it, whilst before the experiment the wire broke when 6·29 kilogrammes were suspended. Edlund found that an iron wire becomes longer when an electric current passes through it, as it ought to do, on account of the generated heat; but the wire assumes its former length gradually when the current is interrupted.

The sounding or clicking of iron bars at the making and breaking of a current that is sent through them is probably also due to mechanical effects. The click is only heard with magnetic metals.

ELECTRO-DYNAMICS.

Behaviour of Galvanic Currents towards each other.—In the history of electricity and magnetism we have stated that Oersted discovered the effects of galvanic currents on the magnetic needle. And both Oersted and the electricians of his time tried to find a connection between electricity and magnetism. Ampère concluded that *if galvanic currents affect a magnet, the earth's magnetism must affect a current.* This led him to the conviction that galvanic currents must influence each other, and he succeeded in proving his theories by experiments. To study the mutual action of galvanic currents upon one another, Ampère constructed an apparatus, the modern form of which

is shown in Fig. 145. From the two screws + and −, metal strips lead to the commutator D, and from here to the pillars B and T. The pillar B has two concentric grooves to hold mercury, and the rod C, which passes up the middle of B, has a cavity at its upper end, also meant to hold mercury. A screw of the pillar B is in connection with the inner groove, and another screw with the outer groove. If on this frame a wire ring be hung so that a point fastened to it rests in the mercury at the top of C, whilst its ends x and y dip into the two grooves holding mercury, a current can be sent through the ring, and the ring itself will be able to turn round the point resting on the rod C. With such an instrument the dynamical phenomena are easily observed. When a current

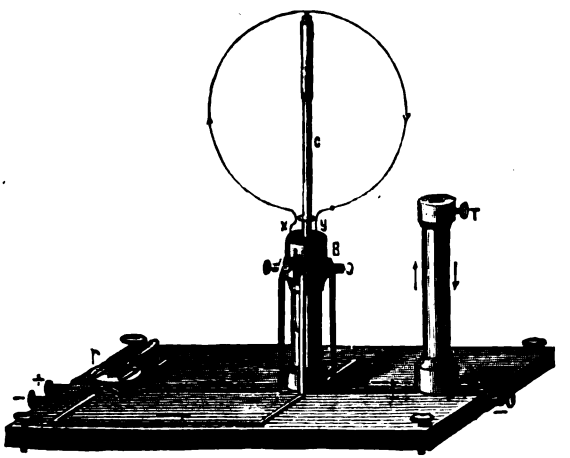


Fig. 145.—Ampère's Circle.

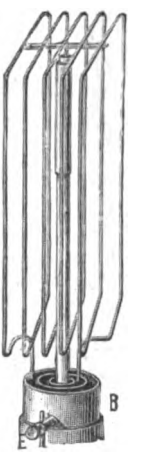


Fig. 146.—Ampère's Rectangles.

is passing through the ring, it strives to assume the same position always, viz., with its plane at right angles to the magnetic meridian, so that the side of the circuit where the current enters points towards the west, and the side where the current leaves the circuit points towards the east. The effects of the earth's magnetism are more clearly seen when, instead of a single wire, several wires running parallel to each other are used. Such an apparatus is shown in Fig. 146.

When our object is simply to study the effects of several conductors upon each other (when a current passes through them), the controlling force of the earth's magnetism might interfere with our plans. This difficulty is overcome by using an apparatus called an astatic frame, shown in Fig. 147. The wire here is bent twice in the form of a rectangle, so that the currents flowing through each rectangle are in opposite directions to each other. The earth's magnetism affects the two rectangles equally, but tends to turn one in one direction, and the other in an opposite direction; it follows that the two

equal but opposite forces counteract each other. The ends of the wire frame dip into the mercury cups *a* and *b*, and the wires from the battery dip into the mercury cups A and B. The direction of the current is indicated by the arrow-heads. If we bring another wire frame, in the form of a rectangle, near this astatic frame, having a current passing through it, so that the wires in both frames are parallel to each other, the two currents will attract each other when both have the same direction, and repel each other when they flow in opposite directions. The attraction or repulsion is indicated by the movable astatic frame, which either moves towards or from the fixed wire frame.

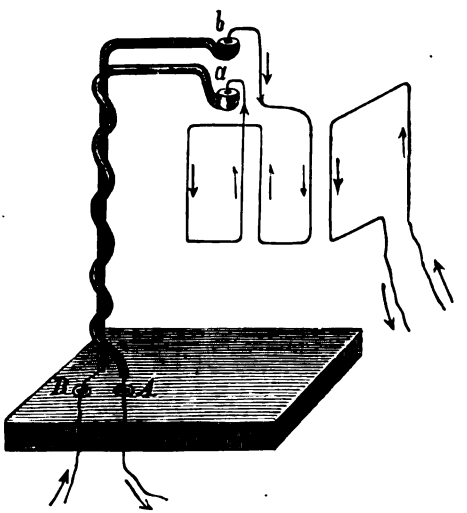


Fig. 147.—Ampère's Astatic Rectangles.

The attraction between parallel currents may be shown by means of Roget's contact-breaker, represented in Fig. 148. One end of the spiral spring F is fixed to the arm A on the stand T, while the other end of the spring dips into the mercury cup G. K_1 and K_2 are screws in connection with the stand T and mercury cup G. If this apparatus be inserted in a circuit, the current will enter at K_1, flow through T A and the spiral F, enter G, and leave the apparatus at K_2. Here the turns of the spiral form a series of parallel currents, which attract each other, causing the spiral to become contracted, and the free end to be lifted out of the mercury, so as to interrupt the current. The instant the current ceases the attractions of the turns cease, and the spiral again dips into the mercury, and so on.

Not only parallel currents, but also currents that cross each other, attract or repel each other. This may be shown by means of the apparatus in Fig. 149. The movable astatic frame is hung upon B (*see* Fig. 145), and the crossing circuit is arranged upon E. The piece *x y* of the astatic frame is made of insulating material. The direction of the current in both cases is indicated by arrow-heads. If, now, the currents both flow towards the vertex of the angle which they make, or both flow from the vertex, they will attract each other. If, however, one of them flows towards the vertex of the angle, the other from it, they will repel each other.

Self-Repulsion of a Current.—Currents, where one A B is flowing towards the vertex (Fig. 150), and the other C D from it, repel each other. The angle itself may have any size, and by making it more and more obtuse, we shall have at last an angle of 180°, and A B will lie in the straight line A′ B′ D;

we then have a conductor in which the current flows from A′ to D, and we are led to the conclusion that the successive portions of one and the same current must repel each other. This may be shown to be the case by the following experiments: C, in Fig. 151, is a wooden trough filled with mercury, which is divided by a partition. The binding screws B B are in connection with the quicksilver on each side of the partition, and are intended to receive the current. On the mercury floats the wire frame F. The current enters at B, flows through the

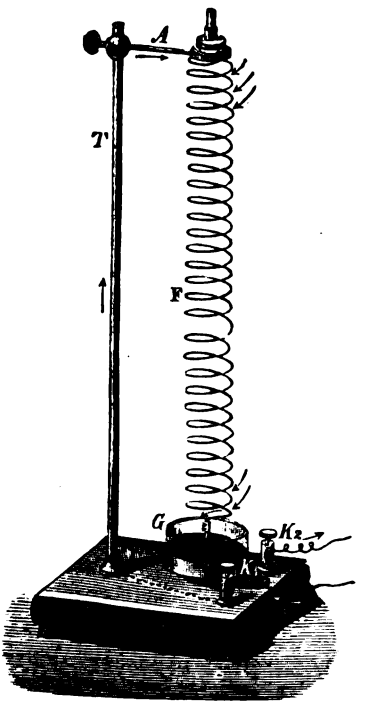


Fig. 148.—Roget's Contact-breaker.

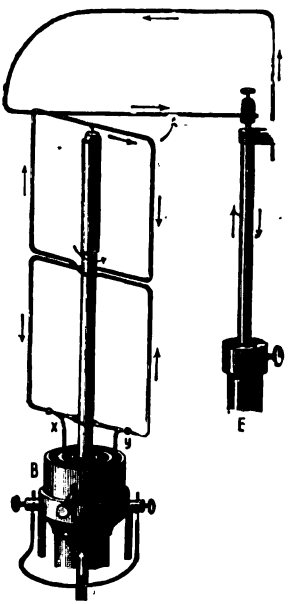


Fig. 149.—Attraction of Inclined Currents.

frame to the mercury of the second partition, and leaves the trough at the second binding screw B. As soon as the current circulates, repulsion becomes noticeable by the motion of the frame away from B B.

Continuous Rotations.—The effects produced by two currents which cross each other may be used for producing continual motion. The wires S and A B, in Fig. 152, have currents flowing through them, the directions of which are indicated by the arrow-heads. If we examine the effect which the piece A C must have upon S, we observe that the currents in A C and S flow opposite to each other; it follows that A C will attract the conductor S in the direction *o c*. If we further notice the directions in S and C B, we find the current in S moves towards *o*, the current in C B flows from *o*; the two currents, therefore, will repel each other

in the direction *o b*. If the conductor S is movable, the result of the effects of A C and C B upon S will be in the direction of the resultant, *o* R. If now the wire A B is bent in the shape of a circle, and if S moves upon an axis that goes through the centre, S will have to rotate in the circle. Under these conditions, the remarks made about the resultant force will apply to every position of S. On this principle the rotation apparatus shown in Fig. 153 is constructed. The stand T has at its upper end a cup containing mercury, in which the conductor L L_1 moves. The lower end of T is connected with *k* by means of a strip of metal. The ends of L L_1 dip in the mercury, which fills the circular groove R, and round this several turns of covered copper wire are wound, the ends being in connection with the binding screws K K_1. The screw k_1 is connected by a metal strip with the mercury in the groove, so that when *k* k_1 are connected with the poles of a battery, the current flows from the binding screw *k* through T to the mercury cup, and then flows through L and L_1 to the mercury of the groove R, and by means of a binding screw k_1 back again to the battery. If the direction of the current is that indicated by the arrow, the conductor L L_1 will rotate with the hands of a watch placed horizontally, that is, face upwards. Rotation effected by repulsion and attraction of parallel currents is shown in the apparatus represented in Fig. 154. The outer

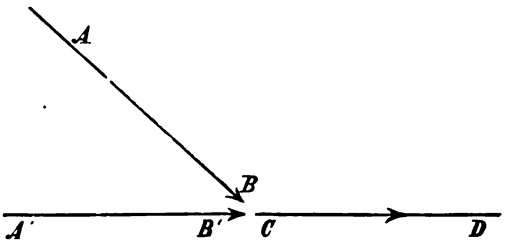


Fig. 150.—Deduction from the Repulsion of Inclined Currents.

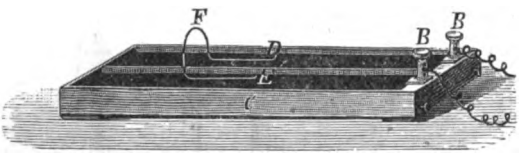


Fig. 151.—Self-Repulsion of a Current.

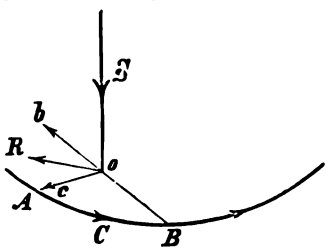


Fig. 152.—Diagram of Forces between Two Currents.

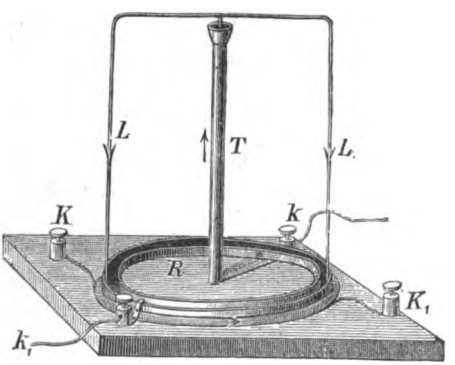


Fig. 153.—Rotation of Current.

circuit is fixed, the inner circuit movable, the ends dipping into the mercury cup H, which is divided into two parts by a partition. The ends of the inner circuit are so arranged that one end dips into one side of the mercury cup H when the other end dips into the other side. When currents are sent through both circuits in the direction indicated by the arrows, being parallel they will attract each other. When the two circuits are, through attraction, brought as near as they can be, which is the case when the two rings lie in the same plane, the wire ends slide over the partition in the mercury trough, and the direction of the current in the inner circuit is thereby reversed. It follows that the two circuits will now repel each other, that is, the inner ring will continue its motion until its right side is close to the left side of the outer ring. Motion would cease now, because currents of the same direction are again opposite each other, but for a repetition of the process of reversal. The wire ends again slide over the partition of the mercury, and instantly there occurs a change of direction in the current; consequently, the inner circle rotates continuously.

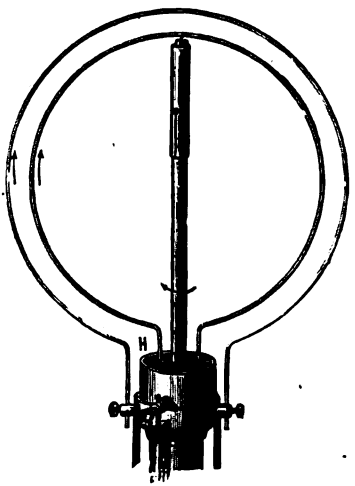


Fig 154.—Rotation of Currents.

The force of attraction or repulsion for two currents is found to be proportional to the product of the intensities of the currents, and to the product of the lengths of the currents, and inversely proportional to the square of the distance between them. If F be the force, c_1 c_2 the currents, l_1 l_2 their lengths, which are everywhere at a distance d from one another,

$$\text{then } F = \frac{l_1 l_2 c_1 c_2}{d^2}.$$

This law is confirmed by the following apparatus:

Weber's Electro-Dynamometer.—The electro-dynamometer is an instrument for measuring the strength of a current by the attraction or repulsion between two parts of the circuit. It consists in the essential parts of two wire coils, of which one is fixed and the other hangs from two conducting wires very near together, so as to furnish a directing couple. The coils carry a small mirror, and for the exact determination of the deviation of the movable coils reflected readings are taken. The two wire coils tend, when currents having the same direction flow through them, to place themselves parallel to each other, as shown in Fig. 154. This construction of a measuring instrument has two advantages, which are especially of importance in practice. First, when one and the same current flows through both coils they experience a deviating couple

proportional to the square of the intensity of the current. Secondly, when through the two coils a current of known strength and direction flows, the movable coil will turn through a definite angle, θ, and assume a distinct direction. If now the current flowing through the two coils be reversed, the movable coil will retain its deviation, the latter being only a function of the strength of the current, but not of its direction. Since at first the direction of the current was parallel in the two coils, it must remain parallel after the change of direction. Later, we shall see that in practice we have to deal with currents which are continually reversing and restoring their directions. For the measurement of such currents the electro-dynamometer is a very useful instrument.

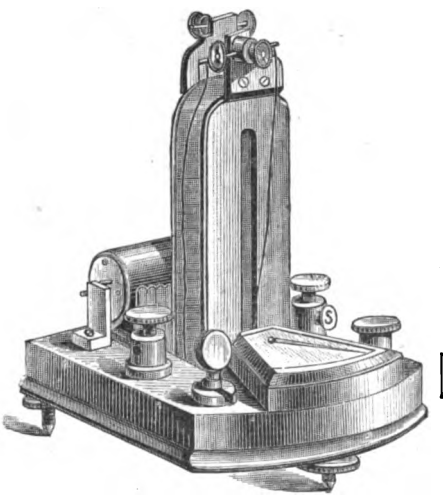


Fig. 155.—Ayrton and Perry's Horse-Power Meter.

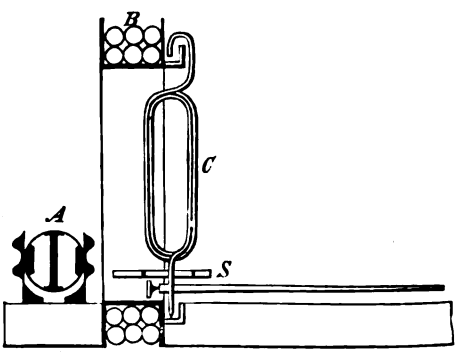


Fig. 156.—Section of the Instrument.

There are two things equal to one another when the coil has found the position of rest: the directing couple, depending on the mode of suspension and proportional to the angle of deviation, and the deflecting couple, depending on the strength of current C_2, and the cosine of the angle of deviation θ. Hence, $C_2 \cos \theta = a\,\theta$ where a is a constant depending on the size of the coils.

Other Electro-Dynamometers.—The instrument shown in Fig. 155, and in section in Fig. 156, is the horse-power meter, by Ayrton and Perry, depending on the principle of the electro-dynamometer. The fixed spiral B consists of a cable of ten wires, which by means of the cylinder A may be arranged in series or parallel; C is the movable coil, S is a spiral spring. The movable coil C possesses a resistance of 400 ohms. The construction of the instrument enables it to give readings directly in horse-powers.

The dynamometer constructed by Siemens for measuring strong currents is shown in Fig. 157. The movable circuit W W has only one coil of thick wire, whilst the fixed coil A A consists of wires having five-and-fifty turns. The

ends of the movable coil dip into mercury cups into which the current is directed: F is a spiral spring which holds the movable coil in position; Z is a pointer attached to the movable coil, and moving over T, a graduated scale. The wire ends of the fixed coil are so connected with the binding screws 1, 2, and 3, and the mercury cups, that the current may be sent either through a few turnings of the fixed coil and the movable coil, or through the many turns of the fixed coil and the movable coil, to adapt the instrument to currents of different strengths. As the movable coil has only one turn, the earth's magnetism will therefore have very little influence upon its position. The deviation of the movable circuit is counteracted by the torsion of the spring, which can be applied by means of the knob at the top. The angle through which the spring has to be moved is the measure of the square of the strength of the current. The instrument is adjusted for measurement according to the usual units by inserting in the circuit at the same time a copper voltameter. From the amount of copper separated out, the strength of the current is calculated in ampères. The motion of the coil being proportional to the square of the strength of the current, the square root of the dynamometer's indication will give the strength of the current; the proportion of this to the strength of current obtained by the voltameter will give the reduction factor, or constant of the instrument, that is, that number which will enable us to reduce the indications of the dynamometer to ampères. This number is called the constant of the apparatus, because, once determined, all calculations may be easily effected by means of it.

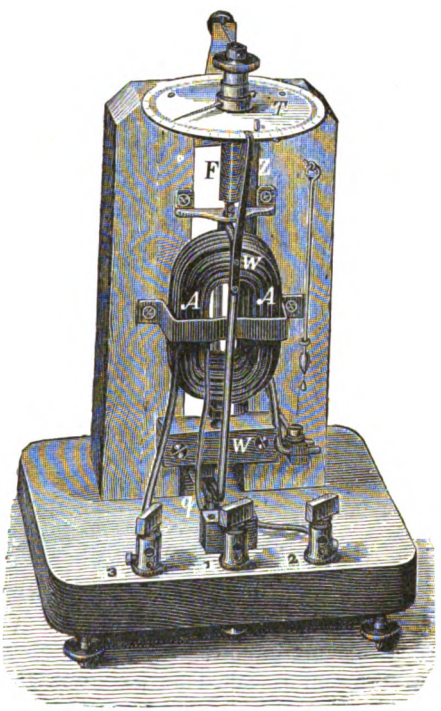


Fig. 157.—Siemens' Electro-Dynamometer.

ELECTRO-MAGNETISM.

Discovery of Electro-Magnetism.—Arago, in 1820, observed that iron filings which were near a copper wire conveying a current surrounded it cylindrically. The wire through which the current flowed did not attract the filings, but gave to them a distinct position; and when the filings were thus directed they attracted each other, and then covered the copper wire. The

current in the copper wire converted each filing into a magnet; and caused these to place themselves with the longest axis at right angles to the direction of the current. The phenomenon disappeared whenever the current was interrupted. Arago found further, that when iron needles were placed in a glass tube round which a current was made to circulate, the needles became magnetic; but the magnetism disappeared as soon as the current was stopped in the spiral. The magnetism was, however, retained after the ceasing of the current when, instead of iron, steel needles were taken. The magnetising power of the current is very evident when the current is made to flow in spiral form round an iron rod. If the rod is of wrought iron, the whole of its magnetism disappears after the current ceases; but if steel be taken, the steel rod only loses part

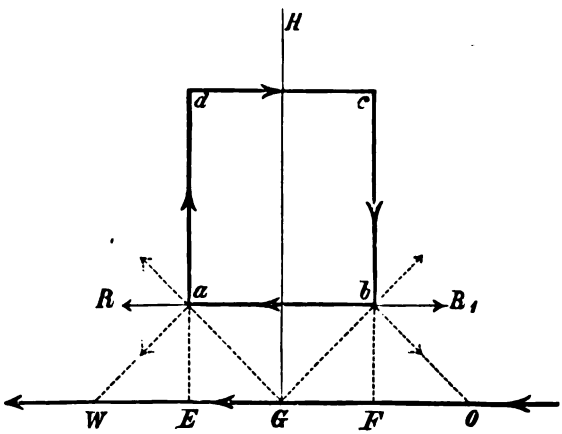


Fig. 158.—A Circuit movable about a Vertical Axis.

of its magnetism after the interruption of the current. The soft iron surrounded by a current is called an electro-magnet, the steel a permanent magnet.

To produce powerful magnets by means of currents, which is the method now usually adopted, the following method was suggested by Elias. A short thick hollow cylinder of covered copper wire is made, and the rod to be magnetised is drawn several times backward and forward, whilst a powerful current passes through the coil. The steel rod is then held fast at its middle, and the current stopped. For the source of electricity a battery consisting of large plates ought to be used, so as to obtain a small internal resistance. The magnetism of the rod increases with the number of turns of wire through which the current flows; and the strength of the current itself, of course, influences the magnetism in the bar.

Directing Power of the Earth's Magnetism on a Movable Coil.—We have had repeatedly to mention the controlling force of the earth upon certain bodies free to move. Let us consider, with the help of Fig. 158, the effects of *earth currents* upon vertical planes through which electric currents are

passing. Let *a b c d* represent the circuit movable round a vertical axis H G, and let W O be the resultant of all the earth currents, which we will call, in short, the earth current. According to Ampère's theory, this current must be at right angles to the magnetic meridian from east to west. As every such circuit compared with the earth circuit is infinitely small, the difference in the distances of currents *a b* and *d c* from O W need not be considered further, the currents in *a b* and *d c* are of equal strength and opposite directions, and therefore it follows that the effect which the earth current has upon the horizontal currents *a b* and *c d* is equal to O. It is, however, different with the vertical currents *a d* and *b c*; these stand in the same relationship to the earth current as the current

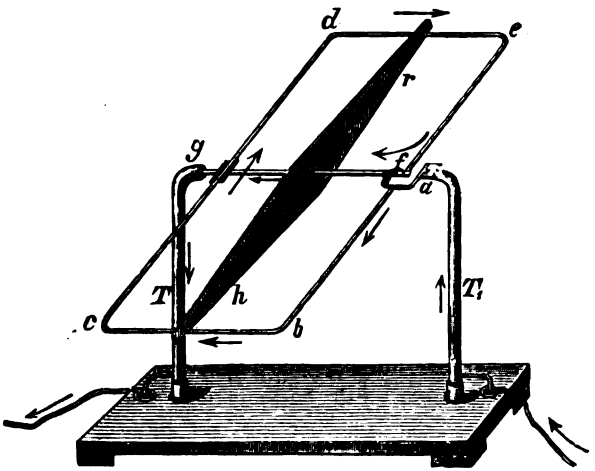


Fig. 159.—A Circuit movable about a Horizontal Axis.

S stands to current A B in Fig. 152 (page 166). Currents *c b* and O W will cut each other in F; *c b* flows towards it, F G from it; hence the two currents will repel each other in the direction G *b*. The currents *c b* and O F flow both towards F, hence they will attract each other in the direction *b o*. The resultant of these two forces will lie in the direction *b* R_1, and will tend to move the circuit in that direction. The currents *a d* and O W cut in E, *a d* and E W flow away from E, and attract each other in the direction *a* W. Again, *a d* flows from E, G E flows towards it; these two will, therefore, repel each other in the direction G *a*. The resultant of these two forces tries to move the circuit in the direction *a* R. The circuit *a b c d* can only move round its vertical axis H G; and the resultants R and R_1 tend to turn the circuit towards different directions, that is, to move it round G H. The circuit will therefore rotate. A single position must be excepted; this position is evidently that of the circuit in which the ascending current lies west, and the descending current east, from the axis G H; in this position of *a b c d* alone the two forces are equal to each other, and their directions, although opposite to each other, fall in one and the same line.

Hence, a movable circuit rotating round a vertical axis places itself always perpendicular to the magnetic meridian in such a manner that the ascending current lies west, the descending one east.

We have next to determine the resultant effect of all the earth currents on a circuit movable like the dipping needle about a horizontal axis. The apparatus devised for this experiment, by Ampère, is shown in Fig. 159. It consists of the wire frame *a b c d e f g*, which is movable round the horizontal axis *f g*. The black pieces where the wires *a f* and *c d* intersect or cross *f g* are made of insulating material. The current is sent through the pillars T T_1. The wooden piece *h r* only serves to support the wire frame, and is so arranged that its centre of gravity lies in the axis *f g*. The apparatus is placed with the axis *f g* at right angles to the magnetic meridian. If a current be passed in the direction indicated by the arrows (T_1 *a b c d e f g* T), the frame will arrange itself at right angles to the direction of dip. The side will be lowest where the current flows from east to west (*c b*) as in the figure. The reason of this is that the currents in these two sides run parallel to the earth current. The laws for parallel currents here apply, and as the earth current flows from east to west, the side *c b*, through which the battery current has this direction, must be attracted. The side *d e*, in which the current has the opposite direction, is repelled. The currents in *b e* and *c d* being opposite, and capable of moving only round the axis *f g*, need not be considered. From the position of the frame, perpendicular to the direction of the dip or inclination needle, it follows that the earth current in our latitudes must flow south.

Earth Currents.—These earth currents have received much attention, although nothing definite as yet has been proved regarding them. There seems little doubt that most of the different magnetic disturbances are due to earth currents. The electrical conditions between the earth and air equalise each other in different ways at different latitudes. In the polar regions, for instance, the aurora borealis is the result of the difference of electrical condition between the earth and air. At the equator thunder-storms are the result.

Influence of the Sun.—Many attempts have been made to find a connection between the spots and prominences in the sun, and the electrical phenomena on the earth. Professor Forster says that by numerous magnetic observations of the last thirty or forty years, it has been proved that the formation of black spots on the surface of the sun, and the generation of pillars and clouds of glowing gases in the immediate neighbourhood of the sun, stand in close connection with certain deviations in direction and intensity of the earth's magnetic forces.

That earth currents may attain considerable intensity during the so-called magnetic storms, was observed on the telegraph circuit of Gothenburg-Nystad during the appearance of the aurora borealis in 1880. Three-fourths of this circuit consists of overhead wires, and one-fourth lies under the surface of the earth, that is, it is a cable. The conductor appeared at times positively charged, and then at other times negatively charged, and produced a deflection in the

apparatus which exceeded the deflection produced by 200 Leclanché's elements. When the conductor was connected to earth, and then again disconnected, strongly glowing sparks were observed to pass, and the wires were heated to such an extent that the gutta-percha covers began to melt. After these and similar observations, and the investigations of the Swedish physicist, Wijkander, there can be no longer any doubt that local fluctuations of the earth current, spreading over small areas only, are due to the inductive action of local thunder-storms. With equal truth it may be assumed that electrical tensions and neutralisations distributed over larger surfaces of the earth, are the causes of the disturbances observed in longer telegraphic currents.

Action of the Earth on Solenoids.—Let us return to the effects of the earth's magnetism on planes free to move, surrounded by currents. Such planes will assume the same position on account of the controlling force of the earth. The phenomenon is produced the more easily when, instead of having

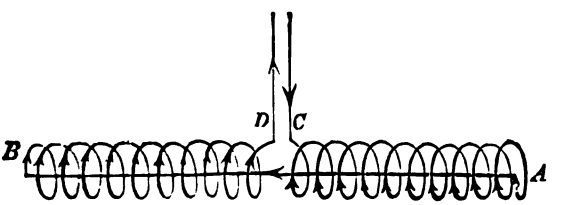


Fig. 160.—The Solenoid.

simply one turn, the circuit has many turns parallel to each other. When a circuit has a form similar to that represented in Fig. 160, it is termed a solenoid. Hence a solenoid may be considered as a system of parallel currents, each turn of which is almost a circle, and is connected by a small piece with the next circle. The sum of all the connecting pieces will be equal to the straight line A B. The direction in which the current circulates in this system is indicated by the arrow-heads. The current in the straight wire A B flows in the opposite direction to that of the connecting pieces between the circle. The effects of these two currents will neutralise each other, and only the circular currents need be taken into consideration. If such a solenoid be suspended so as to move about a vertical axis, it will assume a position parallel to the declination needle. In other words, a solenoid will behave like a magnet; that end will point south in which the current moves with the hands of a watch; the end pointing north will have the current flowing against the hands of a watch. It is usual, therefore, to speak of the ends as the poles of the solenoid, as we speak of the poles of a magnet. If the axis of rotation of a solenoid be arranged as in the circuit represented in Fig. 159, it will assume a position parallel to the dip or inclination needle. When a current passes above or below a solenoid which is parallel to the declination needle, the solenoid will be affected in the same manner as the needle would be. Like or similar poles

of a solenoid repel each other; opposite poles attract each other. The same effects, then, may be obtained by solenoids as by magnets. Even simple currents show the same properties: they, too, are solenoids, but solenoids of very short lengths.

Ampere's Theory of Magnetism.—The evident similarity in the behaviour of magnets and solenoids led to *Ampère's theory of magnetism.* Solenoids and magnets obey the same laws. The force of attraction or repulsion between their poles is directly proportional to the product of the intensities, and inversely proportional to the square of the distance. Solenoid and magnet affect each

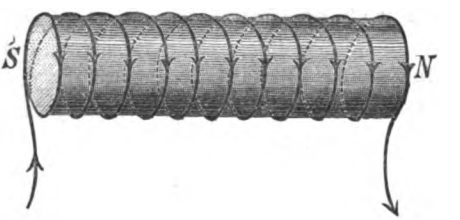


Fig. 161.—Ampère's Notion of a Magnet.

Fig. 162.—Attractive Action of two Magnets.

Fig. 163.—Repellent Action of two Magnets.

other exactly as two magnets would. These phenomena led Ampère to give up his former theory of two magnetic fluids, and to suggest that magnetism is nothing else than parallelism of electric currents. By means of Ampère's theory all magnetic phenomena find a simple explanation; a magnet may be assumed to consist of a bundle of solenoids, with their similar poles arranged in the same direction. According to Ampère's theory, a current at the south pole of a magnet will flow clockwise, at the north pole anti-clockwise, the pole in question pointing towards the observer. If the observer stand before the south pole of the solenoid (Fig. 161), the current enters at S, and flows without altering its direction through all the turns, and out again at N. Place a watch with its face towards the observer, the current will move with the hands; if now the observer moves to face the north pole, leaving the watch in its first position, he will see the current move against the hands of the watch. When the declination needle is at rest the current flows upwards on the west side of the south-seeking pole, and downwards on the east side. If every kind of

magnetism (earth magnetism too) be due to electrical currents, it must be the earth currents which determine the position of the magnet or solenoid. The earth current flows from east to west, and the current at the south pole of the magnet has the same direction at its lower side, and the opposite direction at its upper side.

The attraction and repulsion of magnets are explained by Ampère's theory as the effects of two currents upon each other. The solenoid currents S N and S_1 N_1, in Fig. 162, are parallel to each other, and flow in the same direction, therefore they attract each other. The currents in S N and S_1 N_1, Fig. 163, are parallel to each other, but flow in opposite directions, therefore they repel each other.

Mutual Effects of Galvanic Currents and Magnets.—We know that when a current passes either above or below a magnetic needle, the needle will alter its position. The direction of motion is in accordance with Ampère's rule: Imagine a man swimming in the direction of the current with face towards the needle, the deviation of the needle will take place in such a manner that the north pole will move in the direction of the man's left hand. Fig. 164 represents a circuit with one of its planes parallel to the magnetic meridian; a positive current is sent through it in the direction A B C D E. N S and *n s* are small magnets moving round a vertical axis. Magnet N S, according to the above rule, must reach the position N_1 S_1. To obtain the deviation for the magnet *n s*, we must imagine the human figure lying on its back upon D E, with its head towards E, and its feet towards D. The left arm will then point towards the left of the drawing, and the needle will have to assume the position n_1 s_1. The direction of the needle may further be determined by imagining the solenoids substituted for magnets. The system of parallel currents in the solenoid will be directed by the current through the circuit A B C D E. The solenoid will turn therefore in the direction indicated by n_1 s_1 and N_1 S_1. When the observer stands at the right-hand side of the drawing, the current will be found to circulate in the direction of the hands of a watch. The magnets of

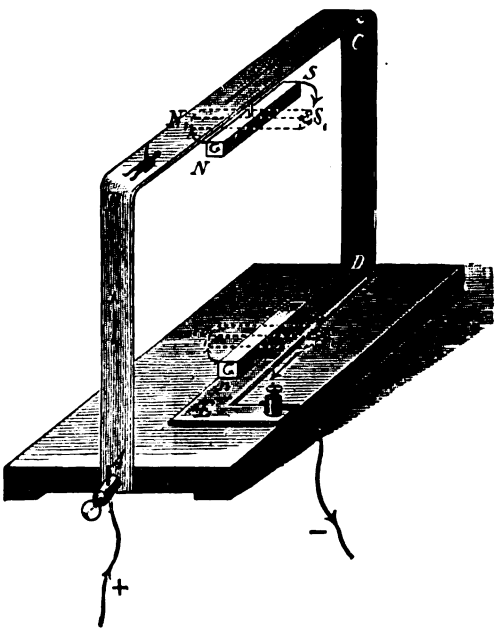


Fig. 164.—Theory of the Action between Current and Magnet.

solenoids have to arrange their circuits parallel to the circuit A B C D E so that those horizontal parts of the circuit which are nearest the circuit A B C D have the same direction as the current in A B C D. Hence, in Fig. 164 the magnet N S must set itself so that its upper horizontal current flows in the direction from B to C, the lower horizontal current in *n s* must flow in the direction from D to E.

Rotation produced by Magnets.—Just as a current affects a magnet, the magnet in its turn influences conductors through which a current passes,

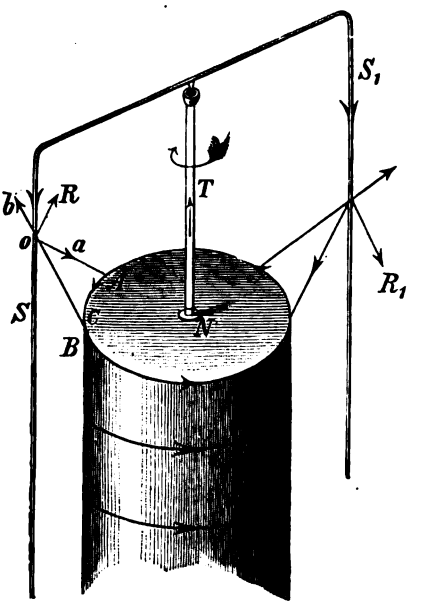


Fig. 165.—Rotation about a Magnetic Pole.

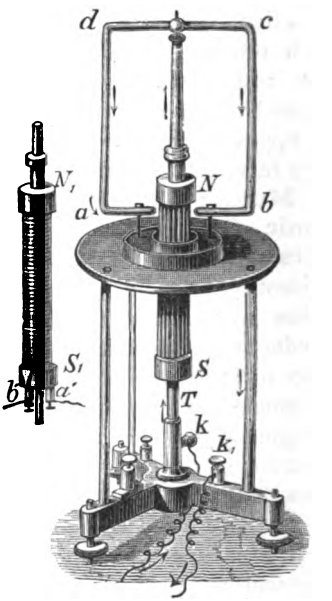


Fig. 166.—Rotation of a Circuit about a Magnet.

and can give to them, when properly arranged, a continuous rotation. An arrangement which will effect such rotation is shown in Fig. 165. If we suppose the current to flow in the direction indicated by the arrows, the conductor $S S_1$ moves round the north pole N of a magnet clockwise. Why this rotation takes place hardly needs further explanation; it is simply again the effect of a horizontal current A B upon a closed circuit S, which brings into action the couple $R R_1$.

In tracing the effects of A B upon S, to obtain the resultant R compare Fig. 165 with Fig. 152, page 166; in both figures analogous parts have the same letters. The whole apparatus is shown in Fig. 166. The metal rod is surrounded by a bundle of magnets N S, with their north poles pointing

upwards. The top of T has a mercury cup, into which one end of the circuit dips. The other ends at *a b* are points, which also dip into mercury. The current is sent through the binding screw K, flows through T, then down *d a* and *c b*, through the mercury to the vertical supports, and out at K_1. The rotation of the conductor takes place in the manner indicated in Fig. 165, through the action of the north pole upon the two descending branches of the current. The south pole, too, will influence them, but being farther away than the north pole, will have less effect. The same result is obtained when, instead of the bundle of magnets N S, the solenoid N_1 S_1 is used. The current may be fixed, and the magnets so arranged as to rotate. An apparatus, in which the rotation of magnets is brought about by a current, is shown in Fig. 167. *a* has a mercury cup, and is connected with the screw *p*. The magnets *n s* and n_1 s_1 are connected with each other by means of a horizontal piece fastened to *b*, which moves in mercury at both ends. The point s dips into the upper mercury cup of *b*, and a wire leading from the horizontal cross-piece dips into the mercury contained in the groove *r*, which is in connection with the stand T and the binding screw p_1. The positive current enters the apparatus at *p*, flows through *a*, then into the mercury at *r*, from here through T, and out at p_1. The magnets move round the axis *a b* in the direction indicated by the arrow.

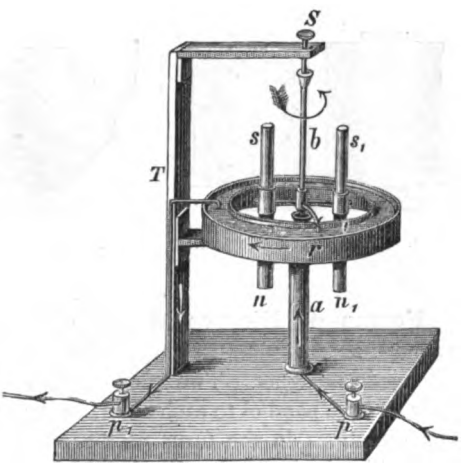


Fig. 167.—Rotating Magnets.

Laws of Electro-Magnets.—Jacobi and Lenz arrived experimentally at the following laws of electro-magnets: (1) The electro-magnetic moment or strength of the magnetism produced in one and the same rod is directly proportional to the number of turns in the coil; and (2) is directly proportional to the strength of the current; (3) is independent of the thickness and material of the conducting wire; (4) is independent of the diameter of the coils. The product of the number of turnings and the strength of the current is called the magnetising force of the spiral.

The more exact experiments made by Müller proved that the above law only holds good when the cross section of the rod does not become too small; and further, that the magnetic moment of a rod cannot be increased beyond a certain point. When very thin rods are taken, the magnetic moment increases more rapidly than the magnetising force. Dub mentioned that the electro-magnetism of a rod is proportional to the square root of its cross section, but

Müller considers this to be correct only so long as the magnetism is proportional to the strength of the current.

Soft iron, poor in carbon, becomes strongly magnetised, but only temporarily; whilst steel, rich in carbon, becomes permanently magnetised. Permanent magnetism increases with the carbon in the iron. As we assume magnetisation of an iron bar to be due to the settling of the molecular currents in parallel directions, the disappearance of the magnetism must therefore be due to the molecular currents again assuming their original mixed directions. In soft iron these changes are brought about very easily, and there is even evidence that when the united currents are released they sometimes go beyond their original line, and produce in the iron what is called reverse permanent magnetism. This phenomenon was observed by Waltenhofen when the magnetising current was suddenly stopped.

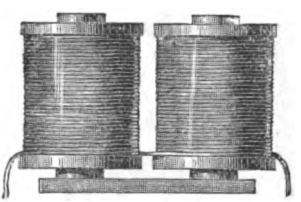


Fig. 168.—Electro-Magnet.

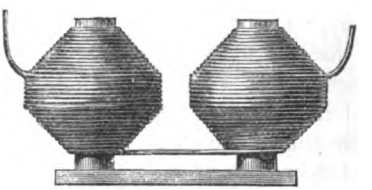


Fig. 169.—Conical Coils.

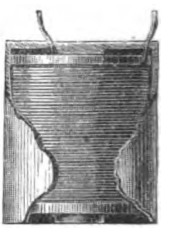


Fig. 170.
Ball Magnet.

Forms of Electro-Magnets.—Different forms are given to electro-magnets, according to the purpose they have to serve. Fig. 168 represents a horse-shoe electro-magnet. Two cylindrical pieces of iron are fastened to a horizontal piece of iron, parallel to each other, and are surrounded by a coil or bobbin of wire. The directions in the turns of the wire are opposite to each other in the two coils. To obtain strong effects with short wires, Thomson winds the wire round bobbins in conical form (Fig. 169). Comacho winds the wire round a thin iron rod, and over the wire he pushes an iron tube, then wraps wire again round the tube, and so on; such a magnet is said to be four or five times as strong as an ordinary one. Fig. 170 represents a so-called ball magnet, a form given to the magnet by Romershausen. It consists of a hollow cylinder closed at one end, into which fits an iron core with wire round it.

For practical purposes it is often necessary that the electro-magnets shall lose their magnetism quickly and thoroughly. The iron core is then not made of one piece, but consists of a bundle of wires, which are insulated; such a bundle, however, will have less magnetic force than a single piece of the same cross section.

Sound produced on Magnetisation.—Page, in 1838, observed that a magnet during the process of magnetisation by the current emitted sounds. Ten years later Wertheim investigated the subject. In the circuit which he used

for magnetisation an automatic contact breaker was inserted. He then found that the pitch of the sound was independent of the number of interruptions. Changes in the thickness of the rod had also no effect. Johann Philipp Reis caused the oscillations of a contact breaker to synchronise with the vibrations producing a sound; he then obtained a sound from the iron bar the pitch of which was equal to the pitch of the sound interrupting the current. On the basis of this he constructed his telephone, and exhibited it in 1861 to the Scientific Society of Frankfort.

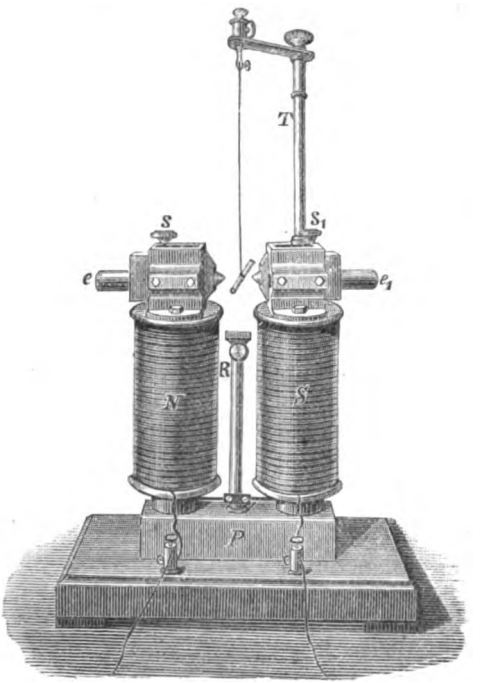


Fig. 171.—Apparatus for Diamagnetic Experiments.

Poggendorff obtained very strong galvanic soundings when he placed a cylinder of sheet iron, open at one side, over a vertical magnetised spiral. Wertheim observed that an iron bar becomes longer through magnetisation. Alfred Mayer took the subject up (1874), and found iron rods as well as steel rods become suddenly longer during the first magnetisation; that after the magnetising current ceases an iron bar gradually assumes its original length, but a steel rod becomes again suddenly shorter. Repeated magnetisations cause elongation in the iron bars, but shorten the steel bars. The shortening of the iron rods when the current ceases is not so great as the lengthening when the current commences.

DIAMAGNETISM.

Magnetic and Diamagnetic Bodies. — By using very powerful electro-magnets we find that not only is iron affected by them, but also other bodies. Those bodies are called paramagnetic which are attracted by both poles of the magnet, and those bodies are diamagnetic which are repelled by both poles. Faraday, in 1845, pointed out that almost all bodies can be placed under one or other of these heads. To determine to which group a substance belongs very powerful magnets have to be used. Fig. 171 shows an apparatus for diamagnetic determinations. On the iron cross-bar P the two magnets N and S are fastened. Pieces of soft iron are screwed to the poles,

and into these pole-pieces are inserted the pointed iron cylinders $e\ e_1$, which can be adjusted by means of the screws $s\ s_1$. Objects to be examined may be either placed upon R, the top of which is movable, or suspended from T. An iron bar brought between the poles of this instrument will set itself in the line of the poles; or, as Faraday called it, axially. If bismuth be taken instead of iron, it places it across the line of the poles, or equatorially. By similar experiments Faraday arranged the following list:

Paramagnetic: Iron, nickel, cobalt, platinum, manganese, chromium, etc.
Diamagnetic: Bismuth, antimony, zinc, cadmium, mercury, platinum, silver, copper, gold, arsenic, uranium, etc., phosphorus, sulphur, iodine.

The salts and oxides were also examined, and it was found that compounds of iron, nickel, cobalt behaved paramagnetically, with the exception of ferrocyanide of potassium, which is diamagnetic. Plücker for this purpose made the tops of his magnets flat, and placed upon them water-glasses holding the liquids. The

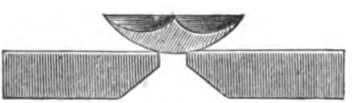


Fig. 172.—Paramagnetic Fluid.

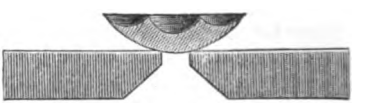


Fig. 173.—Diamagnetic Fluid.

paramagnetic fluids assumed the form shown in Fig. 172; the diamagnetic fluids, the form in Fig. 173. Water proved to be strongly diamagnetic.

It is a peculiar phenomenon that magnetic bodies change their character when the surrounding medium is altered. For instance, paramagnetic bodies surrounded by stronger magnetised bodies become diamagnetic; and diamagnetic bodies surrounded by stronger diamagnetic bodies become paramagnetic. Gases and vapours were also examined. Faraday made gases mixed with a little HCl rise between the poles of the electro-magnet; tubes for holding the gas were arranged axially and equatorially. The tubes contained ammonia gas, and the white fumes produced when HCl and ammonia mix indicated whether the gas was paramagnetic or diamagnetic. Gases were also enclosed in soap bubbles and thin glass globes. In air most gases proved to be diamagnetic: oxygen, however, was paramagnetic. Oxygen enclosed in a thin glass globe is strongly attracted, hydrogen strongly repelled. Flames, too, are influenced. An iron bar when near a magnet is attracted, because the magnet induces opposite magnetism in the end nearest to it, which leads to attraction. The reverse will take place in a bismuth rod. Weber constructed an instrument, the diamagnetometer, by means of which he measured the magnetic moment of bismuth; and he found it to be 1,500,000 times less than that of a piece of iron of the same size.

The fact that diamagnetic bodies can assume polar conditions explains the magnetic behaviour of bodies in different mediums. If, for instance, the medium be diamagnetic and the body to be examined also diamagnetic, in the line of

each magnet both the medium and the body will have the same polarity. The poles of the magnet try, therefore, to repel both and to place them equatorially. The medium, too, on account of its polarisation, tries to repel the body and to arrange it equatorially to the medium and axially to the pole. Hence, although the body belongs to the diamagnetic substances, in the diamagnetic medium it may appear paramagnetic. Whether the medium or the poles have the predominating effect depends upon the strength of the magnetic force which has been given to the medium and body. If a body and medium show similar magnetism, and the medium is more strongly para- or dia-magnetic than the body, the body will show opposite magnetism in this medium to that exhibited in a medium more weakly para- or dia-magnetic than the body.

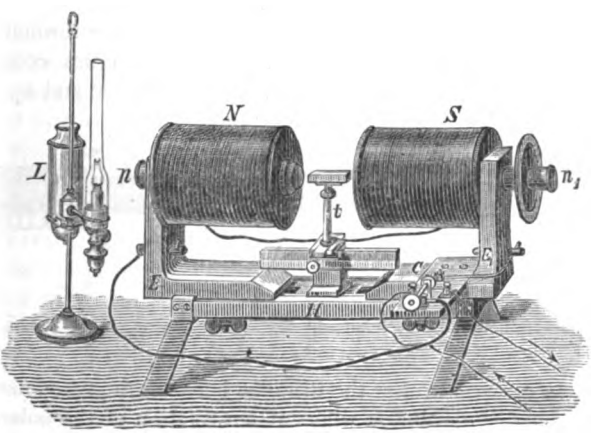


Fig. 174.—Action of a Magnet on Polarised Light.

Spheres made of magnetic substances assume no distinct position between the poles of a magnet, as their mass is regularly distributed in all directions; if, however, balls be made of certain crystals, they will arrange themselves with their optic axes either axially or equatorially. Faraday, who attributes this phenomenon to a peculiarity which the crystals possess, calls it magnetic crystal force.

Rotation of the Plane of Polarisation of a Ray of Light.—Faraday discovered that a powerful magnet is capable of turning the plane of polarisation of a transparent medium. A ray of light is said to be polarised when it can be reflected at the surface of glass in one position, but not in another; or when it can be transmitted through a plate of tourmaline in one position, but not when the plate is turned at right angles to this position. Ordinary light can be reduced to this condition by passing it through what is called a polarising apparatus. A Nicol prism or a thin slice of tourmaline will answer the purpose. The plane in which a ray is polarised can be detected by observing it through a second polarising apparatus (Nicol prism,

or tourmaline). Every polariser is opaque to rays polarised in a plane at right angles to that plane in which it would itself polarise light. Hence, of two such pieces, one polarises the light, and the other tests the light and shows it to be polarised. The first is called the polariser, the second the analyser.

Faraday, in 1845, caused a polarised ray to pass through a piece of certain "heavy glass" lying in a powerful magnetic field between the poles of a large electro-magnet, through the coils of which a current could be sent at pleasure. Under these circumstances he found that the plane of polarisation was *rotated* in a marked degree.

This rotation of the polarisation plane may be shown by means of the instrument represented in Fig. 174. This arrangement of the apparatus is due to Ruhmkorff. The magnets N S are placed horizontally, with their poles opposite to each other. The iron cores of the magnets have a bore through their whole length. The iron plate which connects the two iron cores consists of three pieces, E H E_1. On the horizontal piece H the two pieces E and E_1, bent at right

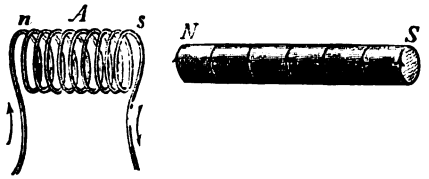


Fig. 175.—Induction by a Solenoid.

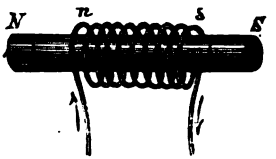


Fig. 176.

angles, are movable, so as to alter the distance between the two poles. The commutator C reverses the current at will. When rotation of the polarisation plane is to be observed, the polariser is placed at *n*, in the bore of the iron core; the analyser, which has a scale, is placed at n_1. The source of light is placed at L, and upon *t* the body under examination. The two Nicols (polariser and analyser) are then so arranged that the field of vision remains dark; when now contact is made, the field of vision again becomes bright. The angle through which the analyser has to be moved to produce darkness again, gives the amount of rotation of the polarisation plane by the magnet. The amount of rotation is proportional to the strength of the current and the length of the column of liquid or transparent medium.

CURRENT INDUCTION.

We have seen that if an iron bar be surrounded by a wire wound in spiral form, through which a current is made to pass, the bar becomes a magnet. Applying Ampère's theory, which we have explained, we say that the circular molecular currents in the rod arrange themselves parallel to the currents in the spiral. This not only happens when the iron rod is inside the solenoid, but also when it is near it. In Fig. 175, A represents a solenoid,

through which the current flows in the direction of the arrows; N S is a soft iron rod. As the currents in the near side of the solenoid flow upwards, the molecular currents in the bar take the same direction. Hence, a north pole appears at N, and a south pole at S. Parallel currents, flowing in the same direction, attract each other; it follows that the solenoid and iron bar attract each other, and if the solenoid be fixed and the iron bar movable, the latter will move towards the former. The nearer the iron rod approaches to the solenoid, the more will the circular currents affect it, and the greater will the magnetism become (provided the point of saturation has not been reached). The strength of the induced magnetism will depend upon the number of turns in the coil, and strength of the inducing current. The force with which the iron bar is attracted by the coil is therefore not merely proportional to the strength of the current. Dub and Hankel proved that this force is proportional to the square of the current. Hence we see that the motion of the iron core produced by the force of attraction of the solenoid is not uniform. As the solenoid approaches the magnet the motion is accelerated, then again diminishes, until in a certain position the rod remains at rest. This is the case when the centres of bar and coil fall together, as shown in Fig. 176. Equilibrium occurs in this position, for the forces of attraction and repulsion balance each other. In the position shown in Fig. 175, S is much farther from the spiral than N; consequently, the attraction between *s* and N must be more powerful than the repulsion between *s* and S. The rod will therefore move towards the coil, the motion continuing until the centres of the rod and coil fall together. The force with which an iron core may be drawn into a solenoid, when properly arranged, may become very considerable, and a solenoid placed vertically is able to hold an iron core in suspension. A. V. Waltenhofen found that a given current produces the greatest effect when the bar is made of soft iron. He further found that the force of attraction of a solenoid is greater on a massive iron core than upon an iron tube, when the current has considerable strength; but if the current be weak, the reverse takes place. This may be proved in the following manner, by means of a balance: From the ends of the balance beam two iron cores are suspended, one solid and the other hollow. Under each of these cores is a coil, the two coils being equal to one another, and having the same current passing through them. As long as the current is weak, the cores are either equally attracted or the beam will move downwards on the side of the hollow core, the result depending upon the thickness of the material in the hollow core. If now the current be considerably increased, the beam moves downwards, on the side of the solid core. We may obtain equality

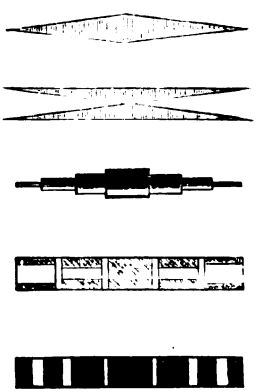


Fig. 177.—Krizik's Bars.

of attraction by varying the number of turns of the solenoid, or the amount of matter of the iron core. By the first process we compensate for an unfavourable position by using a greater number of circular currents; in the second process we compensate for an unfavourable position by bringing a greater magnetic wave into action.

Gaiffe adopted the first plan by arranging the solenoid, not cylindrically, but conically; Fr. Krizik showed the second case by using iron cores, as seen in Fig. 177. If we imagine each of the bars in this figure to be composed of double cones with their bases together, then the force exerted by a solenoid upon any one of them will be uniform for a considerable movement along their lengths. In the second part of this work we shall have an opportunity of studying the effects of these conical helixes and conical iron cores.

Induction on "Make" and "Break."—Electric induction was discovered by Faraday in 1831, in the following manner: A long copper wire was wound round a wooden cylinder, and between the turns of this wire, and insulated from them, a second wire was wound in the same manner. The ends of the first wire were connected with the poles of a powerful battery, the ends of the second wire were connected with a galvanometer. Whenever the current was sent through or interrupted in the first or primary wire, a current was also generated in the second or secondary wire, and was indicated by the deflection of the galvanic needle. The induced current, which was generated by making or breaking contact in the primary current, was sent through a coil wound round some steel needles, and it was found that the steel needles became magnetised; the position of their poles depending upon which of the induced currents was sent through the coil. These experiments proved that induced currents are generated in a conductor forming a closed circuit when a current passing through a neighbouring conductor is made or broken, or has its strength altered; and that the directions of the currents induced on making or breaking contact are opposite to each other.

Induction by Motion.—Induced currents are produced when a conductor through which a current flows is brought near to or taken away from a second conductor forming a closed circuit. In Fig. 178, P represents the smaller or primary coil of stout wire joined to a battery cell E, S the secondary coil of finer wire joined up to a sensitive galvanometer G. Whenever P is lowered or taken away from S, the needle of the galvanometer indicates a current. The directions of the induced currents produced by the different motions of the inducing coil P will be opposite to each other. The induced current produced by approaching S to P flows in the opposite direction to the inducing current of the battery. The induced current produced by removing P from S flows concurrently with the inducing current of the battery.

We have, then, to distinguish four different effects:

1. An induced current is generated in a conductor *b* when a current is started in a near conductor *a*, the direction of the induced current in *b* being opposite to that of the inducing current in *a*.

2. An induced current is produced in a circuit *b* when the current in a neighbouring circuit *a* is broken, and in this case the induced current in *b* flows in the same direction as the inducing current in *a*.

3. When two closed circuits *a* and *b*, one of which *a* conveys a current, are brought near each other, an induced current is generated in *b*, which flows in the opposite direction to that of *a*.

4. When the two circuits are removed from each other, a current will be induced in the closed circuit *b*, which flows in the same direction as the inducing current in *a*.

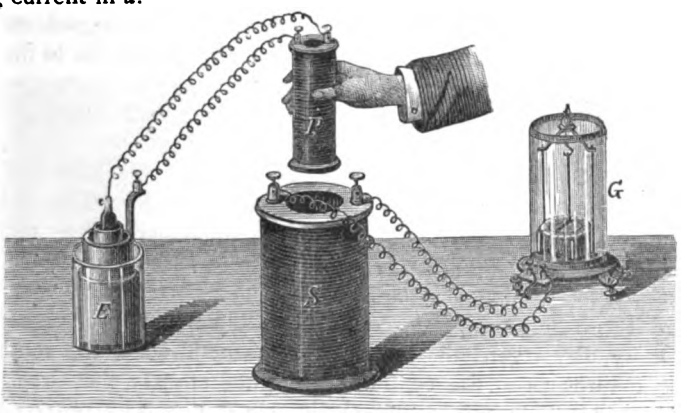


Fig. 178.—Induction by the Motion of a Coil.

Magneto-Electric Induction.—It has been repeatedly said that a magnet may be substituted for a solenoid, and this fact applies to the case of induced currents. Faraday proved this by wrapping one half of an iron ring with a wire, the ends of which were connected with the poles of a battery. The ends of a second wire wound round the remaining half of the iron ring he connected with a galvanometer. Every time contact was made the iron ring was converted into an electro-magnet, the magnetism of which disappeared when contact was broken. It was found that an induced current was indicated by the needle when the magnet was made, as well as when the magnetism disappeared. The induced currents thus obtained were far more powerful than the currents obtained by means of simple galvanic currents. The induced magneto-electrical currents may be produced by using either an ordinary electro-magnet or a permanent magnet with an armature. When the armature is attached or removed, currents are generated in the coil. The produced magnetism generates an induced current, the direction of which is opposite to the molecular currents in the magnet. The previous magnetism generates induced currents in the same direction with the molecular currents of the magnet.

Just as motion of a current towards or from a conductor induces currents, so also by bringing a magnet near to or taking it away from a conductor, induced

currents may be generated. When conductor and magnet move towards each other a current will be induced in the former, the direction of which is opposite to the molecular currents. Move one away from the other, and an induced current is generated that flows in the same direction as the molecular currents. We therefore also distinguish four cases of magneto-induction:

1. When an electro-magnet is made, its magnetism induces in a neighbouring conductor currents of opposite direction to the original currents of the magnet.

2. When the iron is suddenly demagnetised, currents are induced which have the same direction as the molecular or original currents of the magnet.

3. When a conductor, forming a closed circuit, and a magnet are moved towards each other, a current is induced in the former opposite to the original current of the magnet.

4. When a magnet and a closed circuit move from each other, a current is induced which has the same direction as the molecular currents.

Faraday's Conception of Lines of Force.—We have hitherto explained the magneto-electric phenomena by Ampère's theory; there is, however, another method of explaining these phenomena of induction due to Faraday. This consists in looking upon every closed current as a magnetic shell. Let us suppose we are looking at a circle conveying a current clockwise, we may then regard it as having a small magnet in the middle, with a south-seeking pole facing. Or we may regard the circle as a magnetic shell, the south-seeking pole being towards us at the centre. A magnet attracts the circuit as if it were such a shell. This suggests that the phenomena we have observed are due to actions that take place in the medium that fills the space around and between the conductors. Every wire carrying a current has a magnetic field surrounding it, like that of Fig. 8, and every closed circuit acts as a magnetic shell. A solenoid consists of a number of parallel shells. Hence all the actions between two circuits, or between one circuit and a magnet, are thus regarded as magnetic actions, and they can be predicted for any particular case on this supposition. Carry the theory farther, and imagine lines of force drawn through each magnetic shell exactly as in the case of magnets. Then two circuits will tend, like two magnetic shells, to move so as to include as many of one another's "lines of force" as possible. This will be the case when the two wires are parallel in every part, and when the currents run round in the same direction. All the electro dynamic laws of parallel and oblique circuits can be developed by means of the conception of Faraday's lines of force. In order to apply the conception, we have to bear in mind the following properties of the lines of force:

1. Small magnetic particles influenced by the attractions and repulsions in a magnetic field set themselves along, or tangentially to, the lines of force. Hence the resultant force at every point is in the direction of the line of force passing through that point.

2. The lines of force are lines of magnetic induction.

3. A small north-seeking pole placed on a line of force would tend to

move on the line from north to south, and a small south-seeking pole so placed would tend to move from south to north.

4. The lines of force map out the magnetic field. They are thickest where the force is greatest, and the number that strike a given area placed perpendicular to them at any point is a measure of the intensity of the force at that point.

5. There is a magnetic field surrounding every wire conveying a current, the lines of force being circles whose planes are perpendicular to the current.

6. A closed circuit produces a field of force identical in all respects with that of a magnetic shell whose edges lie on the edges of the circuit. The number of lines of force of the shell are the same as the number for the circuit.

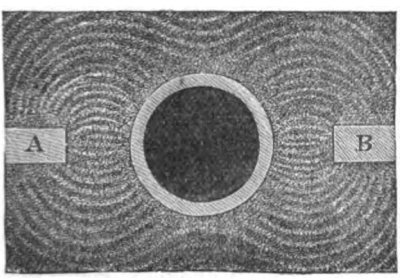


Fig. 179.—Lines of Force and Screened Space.

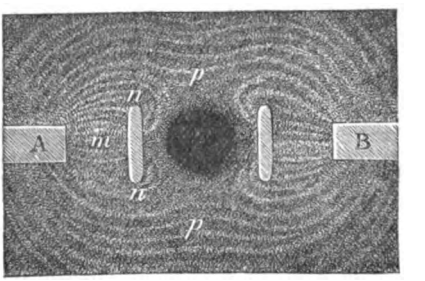


Fig. 180.—Lines of Force and Screened Space.

7. The action of two circuits, or of one circuit and a magnet, on one another is described by the following rule, which is usually called Maxwell's rule: "Every portion of the circuit is acted upon by a force urging it in such a direction as to make it enclose within its embrace the greatest possible number of lines of force. If the circuit is fixed and the magnet movable, then the force acting on the magnet will also be such as to tend to make the number of lines of force that pass through the circuit a maximum."

The same phenomena of magnetic induction are explained equally well by assuming Ampère's molecular current or Faraday's lines of force, though the two theories are not equally attractive for different minds.

Let us refer again to the magnetic figures represented in Figs. 3 and 8, and explained in pages 14 and 15. In Fig. 8, where the faces of the magnetic poles are planes, the lines of force arrange themselves in almost parallel lines between them; this arrangement, however, alters when iron is brought between the two poles. Figs. 179 and 180 will facilitate our explanations: A and B represent the poles of a magnet between which a tube made of wrought iron is placed. The lines of force are made visible by iron filings. In Fig. 8 the lines of force between the two poles are very close together, whilst in Figs. 179 and 180 no lines of force are to be observed in the centre. The iron here acts as a kind of screen, to prevent the lines of force from entering the space occupied by it. The iron in such a case is called a *magnetic screen*. When the iron body brought

into the magnetic field is of the form of a very short tube or ring, the screen effect is not so perfect. The lines of force partly enter the space occupied by the iron ring, they go over the edges of the ring and then bend backwards, as shown in Fig. 180. The screen effect of the cylinder can be produced by induction also. A wire is wound round the iron tube in such a manner that one end will be in the inside, the other end at the outside of the cylinder. If this coil now be moved along the periphery of the iron tube which is at rest, an induced current will be the result, the direction of which depends upon the position of the coil. Each turn of the coil moving from the equatorial into the axial position passes through a field where the lines of force are condensed, the other half of the turn moves through a field of but slight intensity; as one half of the turn cuts more lines of force than the remaining half of the turn, a current is the result, the intensity of which is determined by the difference of the number of intercepted lines of force. The same current is obtained when both turns and iron cylinder are rotating, the cylinder moving round its own axis the same as in the Gramme machine. By the rotation of the cylinder round its own axis the distribution of the lines of force is not altered in the field, neglecting the influence which the permanent magnetism of the iron might have. This one example of the Gramme machine shows clearly that, to construct electric machines, distribution of the magnetic lines of force in the field must receive due attention.

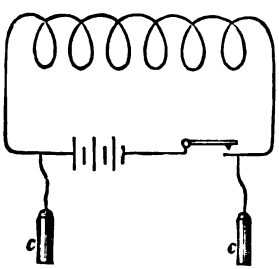


Fig. 181.—Self-Induction of Current.

Induction by one part of a Circuit upon another part of the same Circuit.—Currents may induce currents in their own circuit; such induced currents are called by Faraday extra currents. The existence of extra currents may be proved as follows: Into the circuit of a battery a coil is introduced with an arrangement for breaking contact. The circuit also has two metallic handles *c c*, shown in Fig. 181. During contact the current flows evenly in the circuit, but if contact be broken while a person holds the metallic handles, a shock will be experienced, owing to the induced extra current. Another arrangement for the same purpose is shown in Fig. 182. Wires lead from the battery B to the coil S, and from the points of the circuit indicated at *a* and *b* wires branch off to the galvanometer G, so that the galvanometer forms a kind of shunt. When contact is made, the current flows from the battery towards *a*, and divides here into two branches: one branch flows to the galvanometer, the other branch flows through S, meets the first branch at *b*, and both return to the battery again. This current is indicated by dark arrows. The deflection of the needle which this current would cause is prevented by fixing a pin in front of it. The branch current cannot now deflect the needle, it only causes it to press against the pin. When contact is broken, however, a current flows through the coil S, and causes the galvanic needle to move in the opposite

direction to that of the pin. The extra current in the figure is shown by the dotted arrows; this current enters at the left hand of the galvanometer, whilst the direct current previously entered at the right. The extra currents weaken the primary currents, and cause a delay of from 0·166 to 0·2 second in long circuits before the current attains its full strength. The extra current makes its appearance as a bright spark at the moment of breaking circuit. If the circuit be coiled up, especially if it be coiled round an iron bar, as in an electro-magnet, then on breaking circuit there will be a brilliant spark. This extra current on breaking

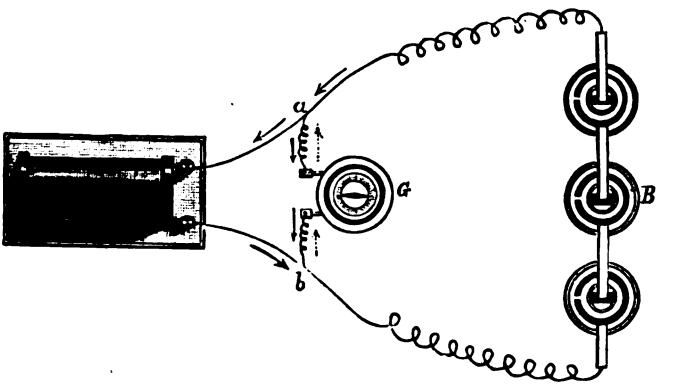


Fig. 182.—The Extra Current.

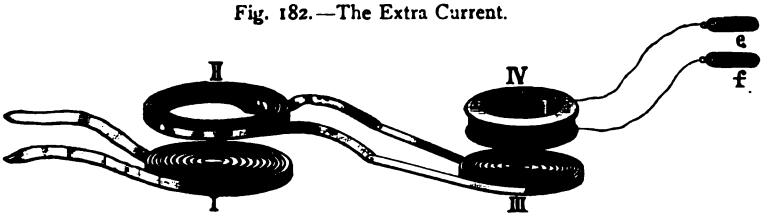


Fig. 183.—Higher Orders of Induction.

circuit has a very high electromotive force. The extra current due to self-induction, on "making" circuit, is an inverse current, and gives no spark, but, as we have said, prevents the battery current from rising at once to its full value. The extra current on breaking circuit is a direct current, and therefore increases the strength of the current just at the moment when it is about to cease.

Higher Orders of Induction.—The similarity in the effects produced by galvanic and induced currents led to the idea that induced currents in their turn must be capable of inducing other currents in conductors near them. Henry proved this to be the case by using several coils of copper bands parallel to each other. Fig. 183 (I II III IV) shows how he arranged them. Making or breaking contact in I induced a current in II, which flowed also through III; the wires of IV terminated in metallic handles *e f*, and the person touching *e f* received a shock due to the induced currents in IV. Induced currents of this

kind are said to be of a higher order. The induced current of IV is one of the second order. Currents of a higher order cannot very well be simple currents, as the appearance or disappearance of the inducing current causes two induced currents; the direction of the following induced current would be opposite to the preceding. Let us suppose the current produced in I positive, the direction of the current in II will be negative; this induced current flows through III, and induces in IV two positive currents of the second order, viz., one positive and one negative. When the positive current in I starts, a negative transitory current in III begins and instantly subsides. While it increases it induces a positive current in IV, and while it decreases it produces a negative current in IV. When the current in I stops, in a similar manner it causes a transitory positive current, which in increasing and decreasing causes opposite currents in IV. If these currents be led to a fifth coil, induced currents again would be produced in a sixth coil, and as each of these induced currents of the second order produces two induced currents of the third order, four induced currents of the third order will be generated, and so on. In this manner, by proper arrangement of the coils, induced currents of a fourth and fifth order might be obtained and proved by their physiological effects.

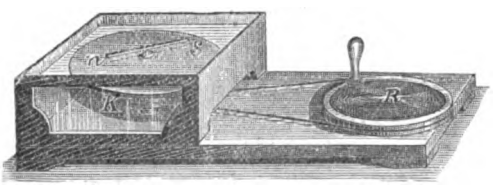


Fig. 184.—Arago's Rotations.

The earth's magnetism induces currents when closed circuits are made to move so as to cut the lines of force. This kind of induction, too, was first observed by Faraday. He connected the ends of a coil with a galvanometer, the coil being so arranged that its plane stood at right angles to the dip or inclination needle. When the coil moved through 180°, the deflection of the needle indicated the current induced by the earth's magnetism. The effect is increased by multiplying the turns of the coil, and by placing iron cores within it. We may here mention that a Siemens' dynamo-electric machine can be set in motion by currents induced by the earth's magnetism.

Arago's Rotations.—A number of interesting induction phenomena were observed as early as 1824 by Arago, and called after him Arago's rotations. He found that when a disc of copper is made to rotate in its own plane, and a magnetic needle is placed over it, the needle turns round in the same direction as the disc. The apparatus is shown in Fig. 184. The copper plate K is enclosed in a glass case, and can be made to rotate rapidly by means of a multiplying wheel R. Above the horizontal glass plate of the case the needle *n s* moves freely upon a pivot. The velocity of the needle increases with the velocity of the disc. If the copper plate be perforated the effect is diminished. Variations of the effect are obtained by substituting different metals for the copper plate.

If the magnet is fixed, it will impede the motion of metallic matter near it. The effect of fixed magnets upon rotating metallic bodies can be shown by means of the apparatus represented in Fig. 185 (Foucault's apparatus). The electro-magnet E has, at its poles N S, the armatures *n s* so arranged that the copper disc C rotating about the axis A X can move between them, but not in contact. With a powerful electro-magnet the resistance to the motion of the disc becomes very great.

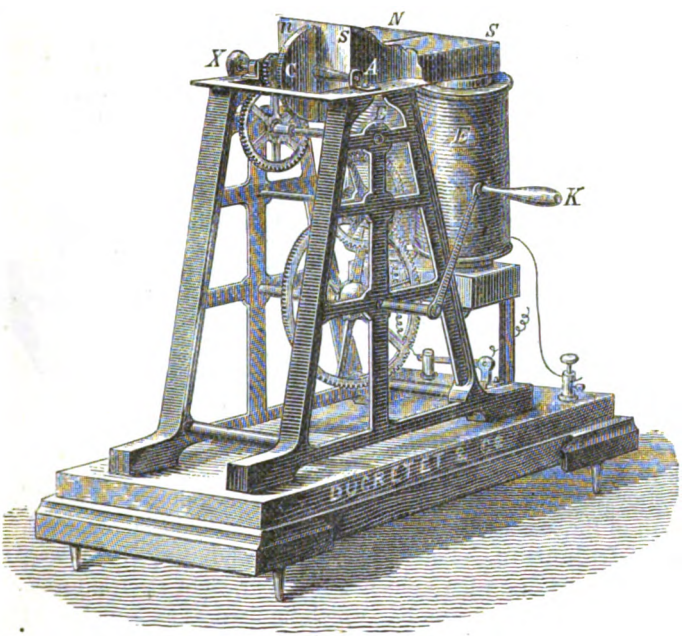


Fig. 185.—Foucault's Apparatus for producing Currents in a Plate.

When the induced current is produced by the motion of a wire in a field of force produced by a magnet, the phenomenon is often described as *magneto-electric* induction; but when the electric current produces magnetism by induction, the term *electro-magnetic* induction is used. In magneto-electric apparatus the coils are moved by mechanical power, in electro-magnetic apparatus the effects are produced by make and break of current without motion of the coils.

There is still another kind of induction, viz., *uni-polar induction*. In all the former magneto-induction phenomena, induced currents were produced by alteration of the magnetism by change of distance, increase or decrease, making or breaking of the current. Induction phenomena are brought about, however, when the magnet only makes a movement near a conductor. Such phenomena

have been shown by Faraday, Weber, and Plücker, by different experiments. One of the forms of apparatus constructed by Plücker, and described by Wiedemann, is shown in Fig. 186. The copper disc *a* is fastened upon the horizontal axis *b c*. The copper disc *a* has the two magnets *n s*; at *f* and *g* metallic springs are fastened, which press upon the edges of the metal discs *b* and *c*. From the screw *h* another spring presses against *a*. When the apparatus is made to rotate rapidly, and *f* and *h* or *g* and *h* are connected with a galvanometer, the needle will indicate an induced current in one or other direction. If *f* and *g* be connected with a galvanometer, the needle will not be deflected. This experiment then is, so to say, the reverse of the experiment made with the

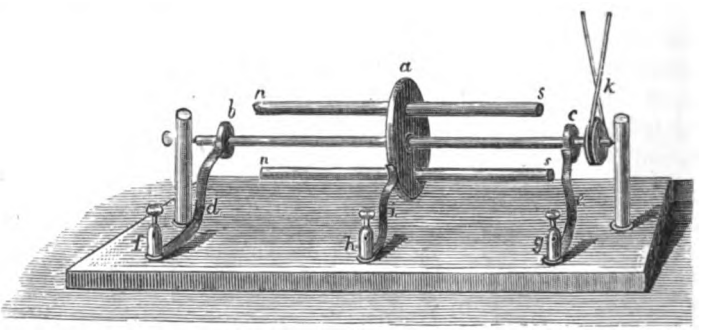


Fig. 186.—Uni-polar Induction.

apparatus shown in Fig. 167. If the current were allowed to flow through the whole length of the axis no rotation of the magnets could be obtained.

Laws of Induction.—Lenz was the first who studied the laws regarding induction. He tried first what influence two, four, eight electric turns of covered copper wire wound round an iron bar, which he used as an armature of a magnet, would have. The ends of the copper wire were in connection with a galvanometer, which indicated the current generated by the disappearance of the magnetism every time the armature was removed. These and similar experiments proved that the currents induced in the coil were proportional to the number of turns in the coil. The same proportionality holds good for E. M. F. when the resistance in the circuit remains the same; it was further found that the E. M. F. of magnetic induction is independent of the distance the turns of the coil are from each other; also of the material and cross section even when, instead of wire, fluids are used, as, for instance, when a solution of zinc sulphate in an indiarubber tube is coiled round the iron.

The laws for electro-magnetic induction and for magneto-electric induction are equivalent. In the first, the E. M. F. of the induced currents is proportional to the product of the strength of the current and to the number of turns in the inducing coil; in the second, of course, proportional to the magnetic moment of the inducing magnet. As has been mentioned already, for the proper adjust-

ment of induced currents it is necessary to take into consideration the resistance in the secondary coil (induced current) and remaining parts of the circuit. It has been found that the strength of the current increases with the conductivity of the wire which has been used for the secondary coil. When the resistance in the remaining parts of the circuit is very great, the strength of the induced current increases with the number of turns in the coil. When, therefore, induced currents are required for purposes where high potential or tension is wanted, the secondary coil also is made of thin wire having many turns. If a not very high tension is required, as, for instance, in machines for electro-chemical purposes, the secondary coil too may have only a few turns of strong wire. The strength of the current is not the same on making contact and when contact is broken. When contact is broken in a circuit, as we have seen, an extra current, having the opposite direction, is generated in the primary circuit; the consequence is the current requires more time to obtain its full strength; the increase of E. M. F. is distributed over a larger interval of time. The E. M. F. increases therefore more slowly, and it follows that the strength of the induced current is not so great.

The duration of induced currents has also to be considered in heating effects. The amount of heat generated by different currents in the same time is proportional to the squares of the currents. It follows that the heat effect of a certain current in a certain time is proportional to the product of the time and square of the strength of current during this time. The amount of heat, therefore, must alter with the duration of the induced current, the E. M. F. and resistance being the same. If we assume the quantity of electricity composing the induced currents to be constant, an induced current of double the duration will have half the intensity. The measure of the amount of heat being the product of the square of the intensity and time (and as $\frac{1}{2} \times \frac{1}{2} \times 2 = \frac{1}{2}$), it follows that the amount of heat generated is inversely proportional to the time. These relations alter when the quantity of the current cannot be considered as constant; but nevertheless the heating effect will always be the greater the shorter the intervals during which the currents last.

The duration of induced currents has marked influence upon their physiological effects. The constant current of a battery only affects our system when a great many elements are used, and the weaker constant currents only affect very sensitive parts. Our nervous system, however, is very sensitive to rapid electrical changes. The induction current, therefore, produces far more powerful shocks than the primary current, because the duration of the former is far shorter than the duration of the latter. The difference of duration in induced currents when massive iron cores or bundles of wire are introduced in the coil explains the marked difference in their physiological effects. By introducing solid matter the duration of the induced currents is increased; by introducing a bundle consisting of many fine wires the duration of the induced current is lessened, therefore the physiological effect is far more powerful. That this is really the case, Magnus proved by introducing a bundle of fine

wires into a coil; the effect was very powerful, but disappeared when by means of a molten metal the fine wires were made to consist of one compact mass. The same result was obtained when the wires were surrounded by an iron tube; and powerful effects were again produced when this tube was ripped open through its whole length.

Lenz's Law.—Lenz, in 1834, summed up the inductive action of currents and magnets by saying, that *in all cases of electro-magnetic induction the induced currents have such a direction that their reaction tends to stop the motion which produces them.* This is known as Lenz's law, and coupled with what we have

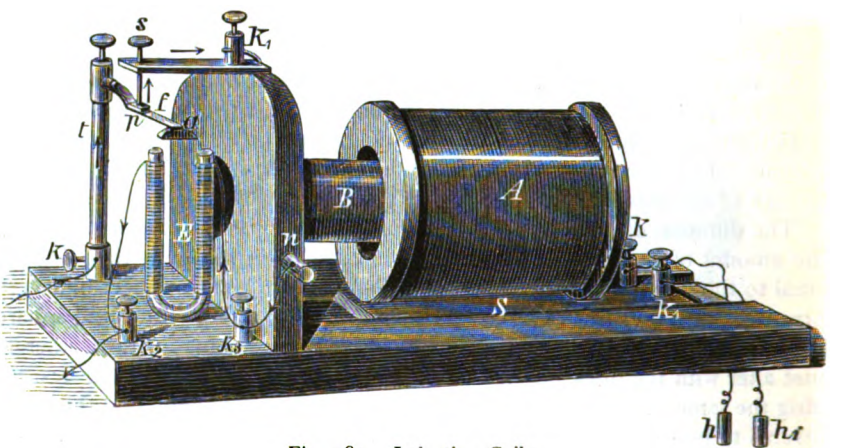


Fig. 187.—Induction Coil.

said on Faraday's lines of force, will be found an easy means of tracing the directions of the currents induced by the motion of coils and magnets.

Induction Coils.—In the foregoing sections we have seen that by means of induction very powerful currents can be obtained, but currents which only last a short time. If we wish to experiment with induced currents, we must find means of generating them in quick succession. Apparatus for this purpose are called induction apparatus. There are two kinds of induction apparatus, magneto-electrical apparatus, and electro-magnetic apparatus. The essential parts of the former are: Spirals with iron cores, which are moved quickly past powerful magnetic poles; the latter consist of a primary coil having an iron core, and a secondary coil which is wound over this primary coil. Through the primary coil a galvanic current is passed, the make and break of which follow rapidly upon each other. The first electro-magnetic apparatus was probably that constructed by Masson and Bréguet. The apparatus shown in Fig. 187 (Du Bois-Reymond's) consists of the bobbin A, round which several hundreds of metres of fine well-covered copper wire are wound. The ends of this wire are in connection with the screws K K_1. This is the secondary coil, or the

coil in which the induced currents are generated; it is fastened upon the movable frame S, which slides horizontally. The primary or inducing coil B consists also of many turns of fine copper wire, and has, as a rule, a bundle of iron wires for cores. Whenever a current is made or broken in B, an induced current is generated in A. By moving A, the inducing effect may be either increased or diminished. To make and break in rapid succession, the apparatus has a contact-breaker or Wagner hammer. This consists of the electro-magnet E, over the poles of which the armature *a* is held by means of a spring. The spring *f* tends to remove the armature from the poles; and in doing so it lifts the platinum plate at *p*, which again presses the screw S. Contact is thus estab-

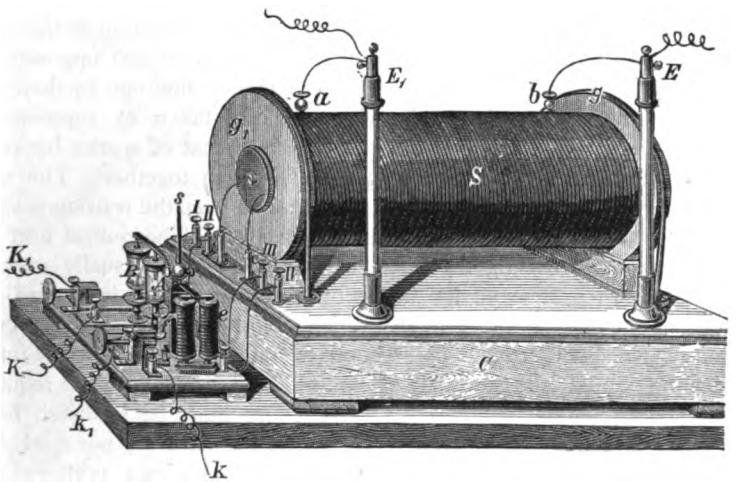


Fig. 188. — Ruhmkorff's Introductorium.

lished, and the current will enter at K, will pass through *t f p s* K_1, through the primary coil B, through *n* and K_3, through the wire of E, and will leave the apparatus at K_2. When the circuit is closed in this manner, the horse-shoe becomes magnetised and attracts the armature *a*. The platinum plate then loses contact with S, and the current is interrupted in the primary coil. The electro-magnet, which loses its power, allows the armature *a* to go back again, and contact is made at *p* as before, etc. etc. Wagner's hammer then causes the make and break of the current in quick succession.

In this manner induced currents at A are generated, which rapidly change their direction; their physiological effects may be felt by taking hold of the handles *h* and h_1. Stöhrer, and especially Ruhmkorff, brought these instruments to great perfection.

Ruhmkorff's Inductorium.—Fig. 188 represents the instrument known as the inductorium of Ruhmkorff. The little apparatus to the left represents the contact-breaker devised by Poggendorff and constructed by Foucault. The

inductorium consists of an electro-magnet excited by a comparatively short coil of thick wire, called the primary coil. A long coil of fine wire, called the secondary coil, is wound round the primary coil, including the electro-magnet. The primary circuit is supplied with electricity by a battery of small resistance, such as a Grove's or Daniell's element. Contact is alternately made and broken with great rapidity. The secondary circuit, when required, is always complete, or interrupted only by such a space that the electromotive force induced in the secondary is sufficient to cause the passage of a spark. When the primary circuit is closed, the electro-magnetism of the core induces a current in the secondary wire in a direction opposed to that of the primary circuit. When the primary circuit is interrupted, the diminution of the magnetism in the core induces a current in the secondary circuit in the same direction as the primary current, and therefore in a direction through the secondary coil opposed to the current previously induced. The currents at "make" interfere by their mutual induction, and means, which will be described, are taken to suppress them. The currents at "break" manifest themselves as a torrent of sparks between the ends of the secondary wires when brought near enough together. The primary coil is, as we have mentioned, made of few turns, to keep the resistance low, and to avoid self-induction of the primary current on itself. The central iron core is for the purpose of increasing the magnetic induction; it is usually made of a number of fine wires, to avoid the induction currents, which, if it were a solid bar, would be set circulating in it, and which would retard its rapidity of magnetisation or demagnetisation. The secondary coil is made with many turns, in order that the mutual induction may be large. The greatest care is requisite in the insulation of the secondary coil. Each wire must be insulated from its neighbour by layers of some hard insulator, which a spark will not easily pierce, and care must be taken so to wind the coil that no two portions of the secondary coil at very different potentials are near together. The electromotive force per foot of the wire in the secondary coil depends on the intensity of the magnetic field produced, and on the rapidity with which it is produced. The sum of the electromotive forces thus induced in a long coil is enormously greater than the E. M. F. of the inducting battery; the longer the secondary coil, the greater the electromotive force. We are not concerned, therefore, to reduce the resistance of the secondary coil, for its E. M. F. increases with the length.

How the apparatus works may be better understood by studying the Fig. 189 (in plan). The essential parts of the machine are: P the primary coil, S the secondary coil, G the battery, A the contact-breaker, E its auxiliary element, C the condenser. E furnishes the current for the contact-breaker. Its course is as follows: From E to the screw k, then through the wire of the electro-magnet e, which is connected with f; then through the metal point which dips in A, through the mercury and metallic bottom of the vessel to the screw k_1, and again back to E. The action of the contact-breaker is very simple. Whenever the current from E flows as described, magnetism is

produced in *e*, and the armature attracted. As one arm *f e* of the lever descends, the other arm, A *f* rises, and causes the metal point to lose contact with the mercury in A. The current is thus broken, the magnet lets the armature go again, and the lever assumes its former position. It follows that the lever will swing up and down, and cause a regular make and break. At B the lever has a second point, which will be connected and disconnected with the mercury in B at the same time as the point at A with the mercury in A. The portion B is inserted into the inducing circuit; it follows that the induced current will undergo make and break at the same time. Let us suppose that B

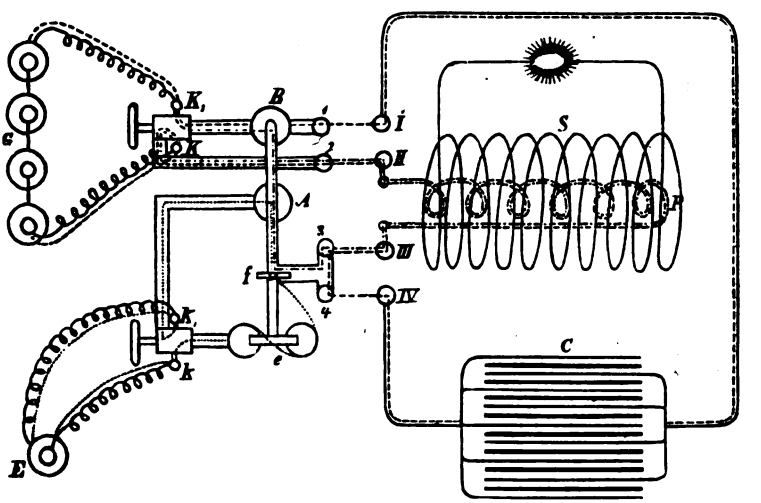


Fig. 189.—Inductorium and Condenser.

dips into the mercury (that is to say, contact is made), the inducing current then has the following direction: From the battery G to K, through the commutator and a copper strip to screw 2, through the connecting wire to screw II, then through the primary coil P to screws III and 3, then to the spring *f*, then through the lever into the metal point, then through the mercury in B, then through the commutator to screw K_1, and then back again to the battery G. The current in the primary coil will make and break contact as often as the metal point touches the mercury at B or leaves it. The primary coil is further connected with the condenser C, which is similar in principle to Franklin's plate, and is made of alternate layers of mica or tinfoil, and oiled silk or paraffined paper, into which the current flows whenever circuit is broken. The object of the condenser is, firstly, to make the break of circuit more sudden by preventing the spark of the "extra current" from leaping across the interrupter; and secondly, to store up the electricity of this self-induced extra current, in order that when circuit is again made the inductive action in the

secondary circuit at "make" shall be reduced to a minimum. This condenser, first used by Fizeau, serves the purpose of producing make and break still more promptly. The greatest induction coil yet made is one that was shown during the Exhibition at Paris in 1881. The apparatus was constructed by Apps. When a current of a thirty cells' battery was passed, a spark of one metre length was obtained.

Luminous and other Effects of Induction Currents.—When the ends of an induction coil are connected with an uninterrupted good conductor, a motion to and fro simply of the induced current takes place. The galvanometer needle shows a deflection in both directions, and if potassium iodide and starch are brought into contact with the ends of the wire, iodine separates out at each pole. If a voltameter be connected with the wire ends, oxy-hydrogen gas is given off at both poles. When, however, the connection of the wire terminals of an induction spiral is *not* brought about by an uninterrupted conductor, phenomena occur which are similar to those obtained by means of electrical machines. The spark, however, consists of the bright and sharply defined spark similar to that obtained by discharging a Leyden jar, and a kind of glow, halo, or aureole which surrounds the bright portion.

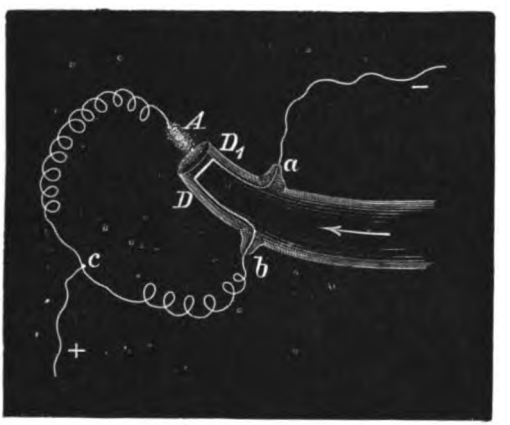


Fig. 190.—Separation of Aureole and Spark.

By means of the apparatus represented in Fig. 190 Perrot showed how to separate the aureole, or glow, from the spark proper in a luminous discharge. In a glass tube, bent as shown, wires are fused at *a* and *b*, so that the ends stand opposite each other at D D_1. The wire leading from *a* is connected with a pole of the inductorium. The wire leading from *b* is connected with the second pole of the inductorium, but from a point of this wire at *c* there passes also the wire *c* A, the end of which points towards the mouth of the glass tube. Through the glass tube air is forced in the direction indicated by the arrow. When now the inductorium is worked, the spark passes between D and D_1, and the aureole appears at A.

When one pole of an induction coil is allowed to touch an electroscope, it will indicate at one time a positive charge, then a negative charge; the explanation for this is the continued change in the direction of the induced currents. When, however, sparks are allowed to pass, the electroscope will give indications of one kind. From these and other facts, it is clear that induced

currents behave differently in a closed circuit and in a broken circuit. In a closed circuit the induced currents flow alternately to and fro. In a broken circuit the density at the poles increases until the balance of the electricities is brought about by a spark. The spark between the poles of an induction coil is analogous to the discharge of batteries; in the former, however, perfect equilibrium of the electricities is not obtained at once, for besides the spark, we have also the aureole. The experiment by Perrot shows that spark and aureole are two entirely different discharges. More minute examinations lead to the detection of further differences. The colour of the spark depends upon the nature of the electrode; it is, for instance, white when iron points are used, green with copper, blue with silver, etc. The colour of the aureole is determined by the medium, and is not uniform throughout. In air or nitrogen the part nearest the positive point is red, the portion nearest the negative point blue. In carbonic acid gas the former appears green, the latter lavender-blue. In hydrogen the whole of the aureole appears red. Frequently near the negative electrode a dark space is observed.

If we make use of a quickly rotating mirror to observe the discharge, the spark appears as a line of light; the aureole appears as a band of light, which is touched on one side by the spark or line of bright light. From this we may conclude that the neutralisation of the two electricities commences with the spark, and that the aureole is formed afterwards. The quick momentary motion in the spark and the slower motion of the electricities in the aureole may be shown by a simple experiment. When spark and aureole are separated from each other, the spark is incapable of igniting cotton soaked in alcohol, etc., whilst in the aureole these bodies begin to burn.

When in the circuit of a battery, consisting of Leyden jars, a galvanometer is inserted, the deflection of the needle which a discharge causes is not influenced by the resistance in the circuit, but the resistance influences the deflection of the needle when inserted in the circuit of an induction coil. The deflection increases with decrease of the sparking distance; the aureole, too, becomes brighter with the decrease of the sparking distance. From all these experiments and observations we may conclude that the spark or neutralisation is an instantaneous discharge of the two opposite electricities, and its luminosity is due to particles torn off from the electrodes in an incandescent state. This spark, therefore, is identical with the spark of a battery. The aureole, on the other hand, is the neutralisation of the two electricities, after the manner of galvanic currents. The luminosity of the aureole depends upon the particles of gas that constitute the conductor. By the passage of the spark the medium (that is, the air) becomes rarefied, and the electricities producing the aureole flow more slowly. This is the reason for the later appearance of the aureole than the spark when observed through the mirror. The changing of colour with the medium and the behaviour of the galvanometer seem all to confirm this explanation. The separation of spark and aureole cannot be effected when a Leyden jar is inserted in the circuit of an induction coil. The

electricities flow to the coatings of the condenser, and from these discharge takes place. With this addition the sparks, when passing, have a greater intensity, and the noise they make is louder. Their colour is determined by the material of the electrodes and the medium by which they are surrounded. For the spectrum analysis of metals this behaviour of the spark is of great importance. The increased spark brings the metals into the condition of vapour, and raises the metallic vapours to incandescence. The colour of the light which these metallic vapours emit simply depends upon the chemical constitution of the metal itself. Our naked eye is not capable of distinguishing the colours, but they are revealed by a glass prism or spectroscope.

Fig. 191.

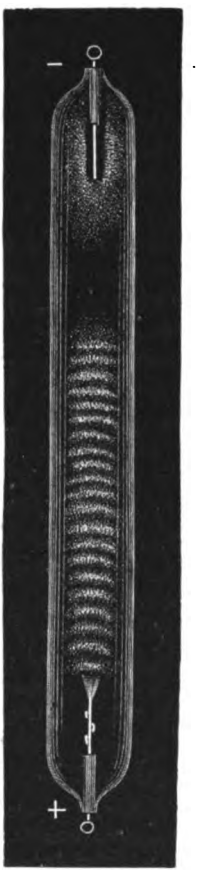


Fig. 192.

Geissler's Tubes.

DISCHARGES IN PARTIAL VACUA.

The voltaic arc and the spark of the induction apparatus alone are capable of changing solid metals into glowing vapours. Induced currents, however, flowing through rarefied gas, will render gases incandescent, and thus enable us to study their spectra. Dry air under great pressure offers a high resistance, but a perfect vacuum is a perfect insulator, and between these extremes there are degrees of rarefication which admit of a flow of electricity, and present many remarkable and beautiful phenomena. Glass tubes partially exhausted are used for this purpose. These so-called "vacuum tubes" are sometimes named, after the most celebrated makers or investigators, Geissler's or Gassiot's tubes. They are usually thin glass tubes with bulbs blown at the end, and more or less twisted into different shapes. They usually have at two different spots platinum wires fused into them. By means of these wires or electrodes, the currents from an electric machine, or more frequently the sparks from an induction coil, are conducted through these tubes, so as to make the more or less rarefied gases incandescent.

Figs. 191 and 192 represent Geissler's tubes. The one narrow at the middle is especially useful for spectrum analysis, as the spectrum in the narrow portion will be more distinct. These tubes are usually sold closed at both ends, filled with gases or vapours at pressures from 2 to 6 millimetres. When currents are passed through a tube like 192, filled with air under the ordinary pressure, a continued stream of sparks passes (provided the inductorium be sufficiently powerful). The aureole is only slightly indicated, and is frequently not visible at all. If now the air in the tube be rarefied, the spark decreases and the aureole increases steadily, until at last the spark disappears altogether, giving place to a kind of brush discharge at the positive pole and a glow or aureole surrounding the negative pole. If the tube contains rarefied nitrogen the brush light appears brick-red or rose-coloured, the glow light blue or violet. In hydrogen the glow is blue, but the light in the narrow part of the tube is crimson. The intensity of the light is different at different places; it is brightest in the narrow portion of the tube.

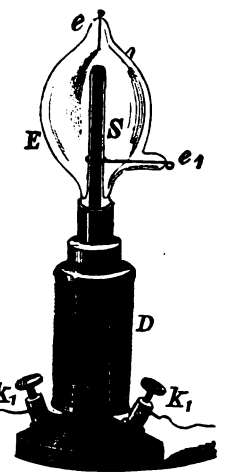


Fig. 193.—Rotation of Light about a Magnet in a Vacuum Tube.

Stratification of Electric Light.—The positive light does not always appear as an uninterrupted brush, but is arranged in layers, or striæ, differing in width and intensity. The striæ appear at the positive pole, and increase in number as the exhaustion increases. This phenomenon takes place both with pure gases and with mixtures. Fig. 192 represents a tube filled with carbonic acid gas under a pressure of two to three millimetres. The green brush light seems divided into regular discs, having their hollows facing the anode. The glow light is lavender-blue, and consists of several bright layers. In tubes containing carbon compounds a bright shining spot is often observed at the anode, from which the layers of light seem to take their origin. This spot or star is probably due to the deposition of carbon particles which are made luminous by the current. Although stratification has received much attention from Gassiot, Spottiswoode, and many electricians, the real cause of this phenomenon is still veiled in obscurity. The labours of Morrens proved to him that the electric spark passes through a mercury vacuum free of other gases, giving unstratified green light, and the spectrum is that of mercury. In gases where the light appears stratified, the distance between the layers increases as the pressure decreases. The revolving mirror shows that the striæ move from the positive to the negative pole. Reitlinger thinks the cause of stratification is due to the fact that the intermittent electric discharges produce impulses by which the substances forming the medium are brought into vibration, at the nodes of which the heavier substances collect. Of the substances thus separated, the non-conducting substances are first brought by the current to incandescence, whilst the better conducting substances remain dark.

Magnets affect the Discharges in Vacuum Tubes.—The effect of a magnet on light produced by induced currents in a rarefied space was first observed by A. de la Rive. In all degrees of exhaustion magnets attract the flames, making them like flexible conductors. The experiment may be made with the apparatus shown in Fig. 193. A rod of soft iron S stands in a glass bulb E, and has a glass test tube placed over it, the edge of which is united with E. S continues downwards, and has the coil D wound round it. The ends of the coil lead to the binding screws K_1 K_1. The electrodes are at e and e_1; the first surrounds the glass tube pushed over S, in the manner shown in the figure.

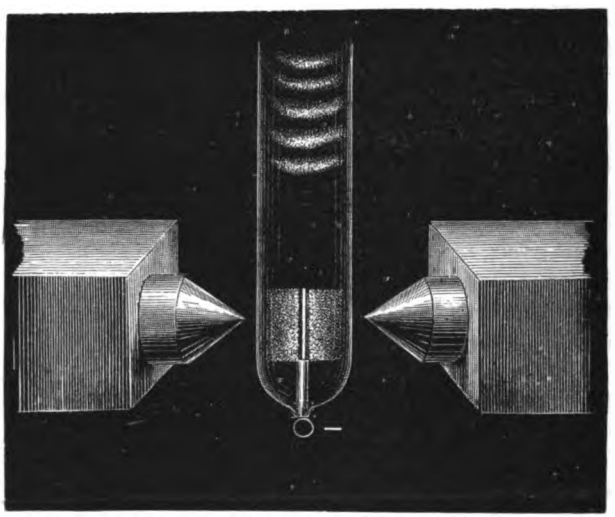


Fig. 194.—Magnet and Vacuum Tube.

The air in E is exhausted to a few millimetres of pressure. When the two electrodes are connected with the poles of an inductorium, the phenomena of the vacuum tube take place. If, however, K_1 K_1 are connected with the poles of a battery, S becomes a magnet, and the light at once begins to rotate about S. The cause of the phenomenon is easily seen: the first induction spark passes in the form of a cloud of light from one electrode to the other, and is deflected by the magnet. The following spark finds now least resistance on the track of the first spark and rather follows the path of the first spark than any other direction; it therefore takes this direction, and is in its turn deflected by the magnet, etc., etc. The sparks succeed each other with such rapidity that the whole phenomenon has the appearance of a cloud of light rotating round the magnet. The direction of rotation round the magnet is the same as that of rigid conductors already described.

Plücker and Hittorf have also studied the effects of magnets on electrical

discharges in rarefied gases, and found that the behaviour of the glow light differs from that of the brush light. If, for instance, a Geissler's tube, such as that represented in Fig. 191, where the glow light is well developed, is placed with its negative electrode between the poles of a magnet, the glow light will assume the shape shown in Fig. 194. In this plane of light (which is named after its discoverer, Plücker's plane) the glowing particles arrange themselves exactly like iron filings: that is, they behave like paramagnetic bodies. The brush light, whether stratified or not, shows an almost opposite behaviour when brought between the poles of a magnet which are equatorially arranged; it is pressed against one of the sides of the tube, and the direction of current and position of magnets determine which side. If tube and magnets be arranged, as shown in Fig. 195, the brush light assumes the position indicated. This deviation may be easily explained by Ampère's swimming rule; imagine the human figure swimming face downwards from + towards −, a

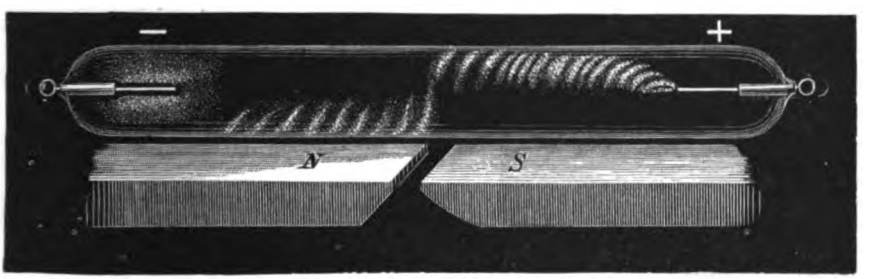


Fig. 195.— Effect of Magnet on Vacuum Discharge.

movable north pole will be deflected to the left. In the case before us, however, it is not the magnet, but the current that is movable, and consequently it deviates in the opposite direction, that is, to the right. The brush light, therefore, will be pressed against the right side of the tube, beyond the north pole, and against the left side beyond the south pole. Dr. Nobanitzky, together with Reitlinger, succeeded in causing the brush light to place itself at right angles to Plücker's plane. The brush in this position has been called the triple fan plane by Puluj, and is represented in Fig. 196. Behind the tube at s imagine the south pole to be placed, and at N the north pole; then the plane lying between N S and the negative electrode *e* represents the glow light brought into the Plücker's plane, and the plane at right angles to this between B and *e* represents the deviated positive brush light. The position of this positive plane of light before or behind Plücker's plane depends upon the position of the magnets, and is determined by Ampère's swimming rule. Magnets not only affect the electrical discharges in luminous gases, but also the striæ. Gassiot observed that a magnet produces stratification in a tube where there has been none. According to Wüllner, a magnet, when brought near a tube containing stratified light, produces new layers, commencing at the positive electrode. Experiments made by Reitlinger and Nobanitzky

showed that to increase the layers of stratification, far smaller power is required than to produce the glow light plane.

The phenomena described up to the present refer to electrical discharges through spaces in which the pressure was from one to two millimetres. If, however, the pressure becomes a fraction of a millimetre, phenomena of a different kind are observed. We followed the phenomena in the Geissler's tube to where the positive brush light is placed at right angles to the negative glow light; the same phenomenon will be more readily produced when the pressure is reduced to 0·8 to 0·5 millimetre. If, however, the pressure is reduced beyond half a millimetre, the layers in the brush light diminish, form irregular balls, and finally when exhaustion is continued disappear. The glow light at the same time expands more and more, in the same proportion as the dark space round the negative electrode becomes larger and larger.

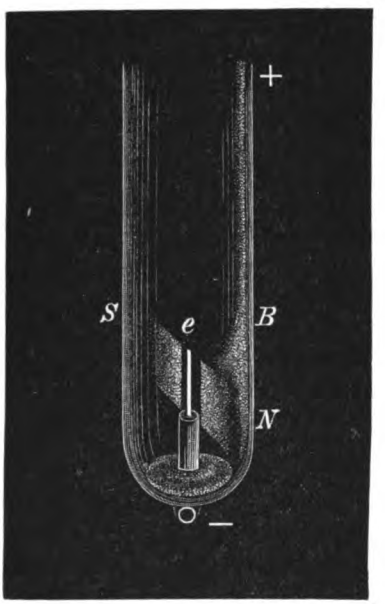


Fig. 196.—The Triple-fan Flame.

Higher Vacua.—For the phenomena occurring in spaces of more complete exhaustion there are two forms of explanation that resemble each other in attributing the flow of electricity to a kind of connection by rarefied particles travelling from the negative to the positive pole. Dr. Puluj considers these particles are of the substance of the negative electrode, while Crookes thinks that they belong to the residual medium. We give Crookes' explanation in his own words:

"If, in the beginning of this century, we had asked, What is a gas? the answer then would have been that it is matter expanded and rarefied to such an extent as to be impalpable, save when set in violent motion; invisible, incapable of assuming or of being reduced into any definite form like solids, or of forming drops like liquids; always ready to expand where no resistance is offered, and to contract on being subjected to pressure. Sixty years ago such were the chief attributes assigned to gases. Modern research, however, has greatly enlarged and modified our views on the constitution of these elastic fluids. Gases are now considered to be composed of an almost infinite number of small particles, or molecules, which are constantly moving in every direction with velocities of all conceivable magnitudes. As these molecules are exceedingly numerous, it follows that no molecule can move far in any direction without coming in contact with some other molecule. But if we exhaust the

air or gas contained in a closed vessel, the number of molecules becomes diminished, and the distance through which any one of them can move without coming in contact with another is increased, the length of the mean free path being inversely proportional to the number of molecules present. The further this process is carried the longer becomes the average distance a molecule can travel before entering into collision; or, in other words, the longer its mean free path the more the physical properties of the gas or air are modified. Thus, at a certain point the phenomena of the radiometer become possible; and on pushing the rarefaction still farther, *i.e.* decreasing the number of molecules in a given space and lengthening their mean free path, the experimental results are obtainable to which I am now about to call your attention. So distinct are these phenomena from anything which occurs in air or gas at the ordinary tension, that we are led to assume that we are here brought face to face with matter in a fourth state or condition, a condition as far removed from the state of gas as a gas is from a liquid.

"When the negative pole is examined while the discharge from an induction coil is passing through an exhausted tube, a dark space is seen to surround it. This dark space is found to increase and diminish as the vacuum is varied; and if the vacuum is insufficient to permit much play of the molecules before they enter into collision, the passage of electricity shows that the 'dark space' has shrunk to small dimensions.

"This 'dark space' is shown in (Fig. 197), which represents a tube having a pole in the centre in the form of a metal disc, and other poles at each end. The centre pole is made negative, and the two end poles connected together are made the positive terminal. The dark space will be in the centre. When the exhaustion is not very great the dark space extends only a little on each side of the negative pole in the centre. When the exhaustion is good, the dark space is seen to extend for about an inch on each side of the pole.

"Here, then, we see the induction spark actually illuminating the lines of molecular pressure caused by the excitement of the negative pole. The thickness of this dark space is the measure of the mean free path between successive collisions of the molecules of the residual gas. The extra velocity with which the negatively electrified molecules rebound from the excited pole keeps back the more slowly moving molecules which are advancing towards that pole. A conflict occurs at the boundary of the dark space, where the luminous margin bears witness to the energy of the discharge.

"Therefore the residual gas (or, as I prefer to call it, the gaseous residue) within the dark space is in an entirely different state to that of the residual gas in vessels at a lower degree of exhaustion.

"In the exhausted column we have a vehicle for electricity, not constant, like an ordinary conductor, but itself modified by the passage of the discharge, and perhaps subject to laws differing materially from those which it obeys at atmospheric pressure."

If we observe a tube through which induced currents have been passed for

some time, metallic films are seen in the inside of the tube, which are well developed in the immediate neighbourhood of the kathode. This phenomenon is caused by the particles torn away from the electrode, and jerked with great rapidity into normal directions. They are charged with statical negative electricity, and bring about the circuit. As every tube, no matter how carefully exhausted, has still a great amount of gas molecules, these two will take part in this so called convertive conduction of the current (circuit). Puluj explains the dark space and kathode light in the following way: The particles charged with statical negative electricity are jerked away from the kathode with great rapidity; this causes the gas particles to be farther removed from the kathode. At the line where electrode particles meet with gas particles, diffusion takes place, and the electrode particles are finally deposited on the glass. When the electrode particles that are moving more quickly meet with the gas particles, further motion is converted into heat and light. It follows that the heat and light effects must be greatest near the kathode, and diminish away from it. The dark space near the kathode is caused by the far more rapid motion of the electrode particles than the gas particles; as the tube throughout has the same pressure, fewer particles must be found in the dark space than in the adjoining light space. The apparatus shown in Fig. 197 may help to make the given explanation clearer. Two small electrodes from the ends of the tube are connected with the positive pole P; the middle electrode, which is of the same size as the cross section of the tube, is connected with the negative pole N of an inductorium. To the right and left of the kathode spreads the dark space; bordering on it we find the kathode light, and the fluorescent and phosphorescent phenomena which always take place when electrical discharges are sent through Geissler's tubes. Many beautiful effects are produced by the richness of the fluorescent rays contained in the light of these discharges. Although these phenomena were known for some time, they were first properly studied by Hittorf, Reitlinger, and Nobanitzky. Tubes having no great rarefication, but made of uranium glass, or surrounded with a solution of quinine or fluorescent liquid, show these effects when the glow light is well developed. But with the higher exhaustion glass itself is phosphorescent. Frequently a beautiful green fluorescence is observed to surround the space of the glow light, which slowly decreases in luminosity

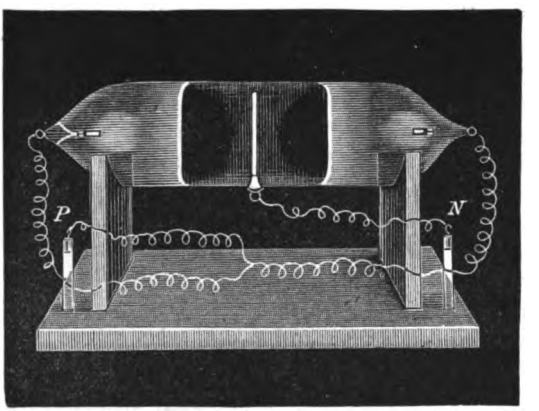


Fig. 197.—The dark Space at the Negative Pole.

towards the brush light. Beyond the dark space where the brush light begins, no fluorescence is observed, owing perhaps to the slight luminosity of the brush light, compared with the more luminous glow light. Again, in tubes highly exhausted, where the kathode light shows very little luminosity on account of the greater rarefication of the medium, very bright green light is observed close to the space near the kathode; by means of magnets this bright green light may be brought to arrange itself in two lines. This latter light, to distinguish it from the fluorescence, was called phosphorescence.*

In Fig. 198 the negative electrode consists of a disc, the positive electrode of an ordinary wire. The tube is so far exhausted that no light is to be seen in it; the discharge goes along the sides of the tube, *i.e.*, in the form of a hollow cylinder. If now this tube be brought between the poles of a magnet N S, an oval phosphorescent ring appears, of the size of the cross section

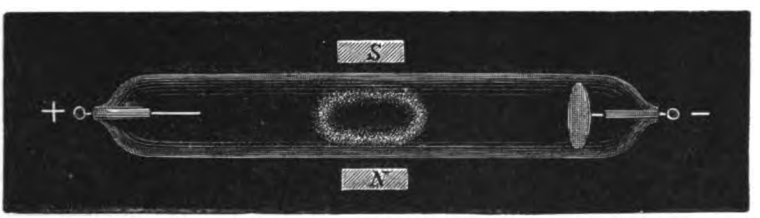


Fig. 198.—Action of a Magnet on a Discharge in a High Vacuum.

of the hollow cylinder. The magnet here has diverted the cylinder, and brought it to the section between the poles. Puluj constructed a lamp, represented in Fig. 199, making use of the phosphorescence in tubes highly exhausted. One of the electrodes has the shape of a rectangle, the other that of a hemisphere, and both are made of aluminium. Above the electrodes a wire is fused into the glass, to support a mica plate s, which has a coating of sulphide of calcium, and has the position shown in the figure. If now the induced current be passed in such a manner that the hemisphere becomes the kathode and the rectangle the anode, the screen s begins to glow with a bright green light sufficient moderately to light up a small room.

Neither the light itself nor the discharge are continuous, but the interruptions of the current follow each other in such quick succession that the eye can see only one continuous glow. If, for instance, we move one hand quickly before the lamp, the hand appears to have more fingers than five. We only see the fingers when light falls upon them; but the light here consists not of continuous rays, but of a number of rays of short duration quickly following each other. Hence we do not see a continuous image of the hand, but a series of images following each other very quickly. Each impression lasts a certain

* By fluorescence is understood the conversion of rays of higher refrangibility into rays of lower refrangibility. By phosphorescence is meant the self-luminosity of a body.

time; the eye, therefore, will still see the second image when the first is still on the retina.

Puluj further constructed an apparatus by means of which it may be shown that bodies made luminous emit light when heated (Fig. 200). At A an aluminium plate is fused into the gas, at S a hemisphere of the same metal, and at B a mica plate is fastened as before. The mica plate has a layer of

Fig. 199.—Phosphorescence of a Mica Plate.

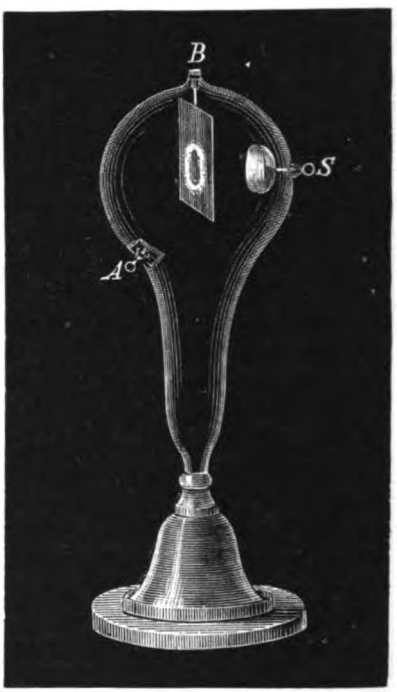


Fig. 200.—Chalked Mica Plate in Vacuum Tube.

chalk on the side facing A. The apparatus was highly exhausted. If connection be made with an inductorium, so that A becomes the kathode, radiant matter will fall directly upon the layer of chalk, which makes the mica plate appear of a deep yellow. If now the poles be reversed so that S becomes the kathode, in the middle of the mica plate a dark yellow spot only is observed, which spreads gradually in all directions; the central part ceases to be luminous, and the whole image produced is similar to that which a stone thrown into still water would produce. If the current be interrupted, and then reversed so that S is again the kathode, *no* yellow spot will make its appearance; the whole phenomenon, however, will be repeated after A has for a short time been made the kathode. The explanation is a very simple one. The glow of the whole

screen, produced when A is the kathode, is due to the phosphorescence of radiant matter. The effect produced is only an indirect one. The hemisphere brings the rays to a focus, and heats the layer of chalk on the other side, causing the phosphorescence at this spot, which spreads gradually in the manner described. This effect, of course, only lasts a certain period, and must come to an end first near the centre where it was started. To prove that radiant electrode matter consists of material particles, Puluj constructed the bulb represented in Fig. 201:—The electrodes are circular discs A and K; A, the anode, serves at the same time as a screen, which causes the phosphorescence to appear in the form shown in the figure at D within the shadow. A small piece of a diamond fixed at D glows in a soft blue light, which is probably due to the reflected particles of the radiant matter.

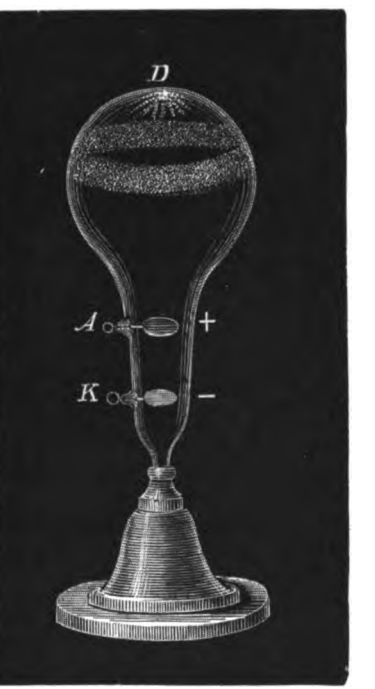


Fig. 201.—Phosphorescence in Vacuum Tube.

There is one particular degree of exhaustion more favourable than any other for the development of the properties of radiant matter which are now under examination. Roughly speaking, it may be put at the millionth of an atmosphere. At this degree of exhaustion the phosphorescence is very strong, and after that it begins to diminish until the spark refuses to pass.

Crookes showed the formation of the shadow by means of apparatus Fig. 202, of which the following is a description:

Radiant Matter when intercepted by Solid Matter casts a Shadow.—Radiant matter comes from the pole in straight lines, and does not merely permeate all parts of the tube and fill it with light, as would be the case were the exhaustion less good. Where there is nothing in the way the rays strike the screen and produce phosphorescence, and where solid matter intervenes they are obstructed by it, and a shadow is thrown on the screen. In the pear-shaped bulb (Fig. 202) the negative pole *a* is at the pointed end. In the middle is a cross *b*, cut out of sheet aluminium, so that the rays from the negative pole projected along the tube will be partly intercepted by the aluminium cross, and will project an image of it on the hemispherical end of the tube, which is phosphorescent. The black shadow of the cross is seen on the luminous end of the bulb *c d*. Now, the radiant matter from the negative pole passes by the side of the aluminium cross to produce the shadow; the glass is hammered and bombarded till it is appreciably warm, and at the same time another effect is

produced on the glass, *i.e.* its sensibility is deadened. The glass has got tired, if we may use the expression, by the enforced phosphorescence. A change is produced by this molecular bombardment which prevents the glass from responding easily to additional excitement; but the part that the shadow has fallen on is not tired; it has not been phosphorescing at all, and is perfectly fresh; therefore if we throw down this cross (which can easily be done by giving the apparatus a slight jerk, for it has been most ingeniously constructed with a hinge), and so allow the rays from the negative pole to fall uninterruptedly on to the end of the bulb, suddenly the black cross changes to a luminous one, because the background is now only capable of faintly phosphorescing, whilst

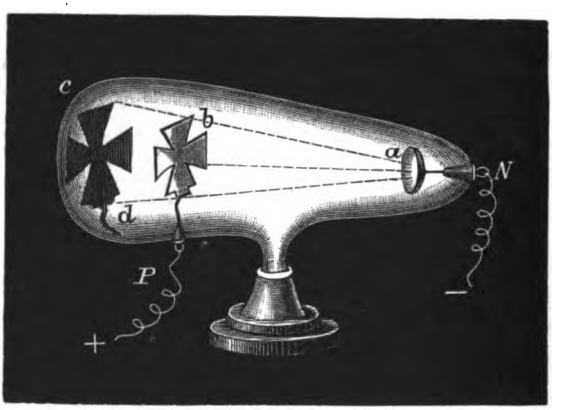


Fig. 202.—Radiant Matter casts a Shadow.

the part which had the black shadow on it retains its full phosphorescent power. After a period of rest the glass partly recovers its power of phosphorescing, but it is never so good as it was at first.

Here, therefore, is another important property of the radiant matter. It is projected with great velocity from the negative pole, and not only strikes the glass in such a way as to cause it to vibrate and become temporarily luminous while the discharge is going on, but the molecules hammer away with sufficient energy to produce a permanent impression upon the glass.

This is Crookes' mode of explanation. Puluj, however, accounts for the phenomenon thus: The parts of the glass beyond the shadow are coated gradually with metal particles, which thus weaken their phosphorescence, whilst the portions of the glass lying within the shadow remain free from this metallic coating. Radiant matter is capable of producing other effects besides phosphorescence. Crookes found that it was capable of melting platinum, iridium, and glass. Puluj constructed a lamp, shown in Fig. 203, to exhibit some of these effects. K, the negative electrode, consists of a hemisphere of 21

millimetres diameter; at a distance of about 36 millimetres from it is a cone of carbonised paper, resting upon a thick platinum wire, which is fused into a glass rod. The glass rod also supports the disc-shaped anode at A. The rays coming from the hemisphere unite at the point of the carbon cone, and bring the latter to a white heat. The exhaustion of the globe and the heating of the carbon must proceed together, because otherwise the gases given off by the carbon would be retained. The most perfect white heat Puluj obtained at a pressure of 0·04. At a still greater exhaustion the heat of the carbon diminishes, and the phosphorescence at the glass sides increases. This may be continued until the carbon remains perfectly dark.

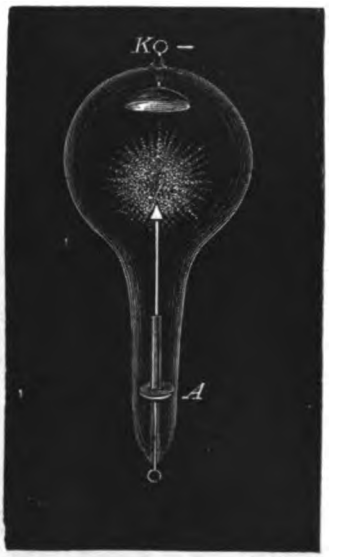


Fig. 203.—Focussing the Heat in a Vacuum Tube.

Repulsion of the Glow by other Bodies.—We have seen what effects magnets will produce on the phenomenon, and we next have to consider whether other bodies, conductors or non-conductors, affect the electric glow. For the purpose of studying repulsion, Reitlinger and Nobanitzky made use of tubes of different shapes filled with either air, H, O, or N. Every gas when exhausted to one millimetre or $\frac{3}{4}$ inch pressure showed the usual alteration. If, however, exhaustion was continued beyond this, repulsion took place when a good conductor was brought near the column of glowing gas. A very marked effect is produced when the pressure for oxygen is reduced to 0·3 millimetre, and for carbonic acid gas to 0·1 millimetre.

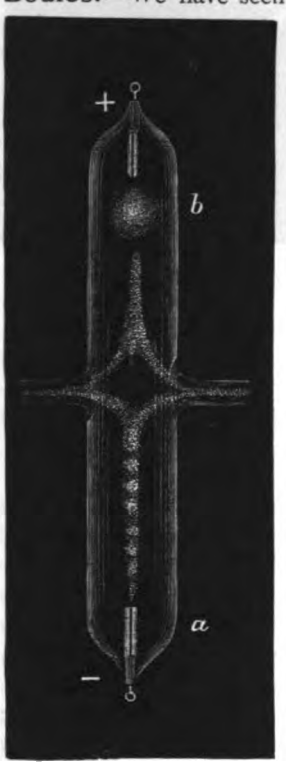


Fig. 204.—The Ball-shaped Glow.

At the positive electrode connected with the + pole of the inductorium, in Fig. 204, a faint image of the glow light is seen (which in carbonic acid is blue). The electrode is surrounded by a thin column of green light, round which a blue glow spreads. At *b*, the positive end of the tube, the green brush light is continued, but next to it comes a blue ball of light, which is separated from the + electrode and the green brush light by dark spaces. In the middle

of the tube the brush light divides, as shown in the figure. The use of the induction coil breaks the continuity of the light, and causes the ball-shaped glow to remain suspended in the middle of the tube; may not this ball-shaped glow represent ball lightning on a very small scale? Repulsion was strongly marked when a conductor (here a brass ball shown in Fig. 205) was brought within 10 to 20 centimetres. The brush light moved as far back as it could. The similarity of this phenomenon with comets, which leave a well-developed tail behind them (*see* Henry's comet, Fig. 206), confirms the view that the tails of comets undergo a real or apparent repulsion by the sun, which has been maintained by

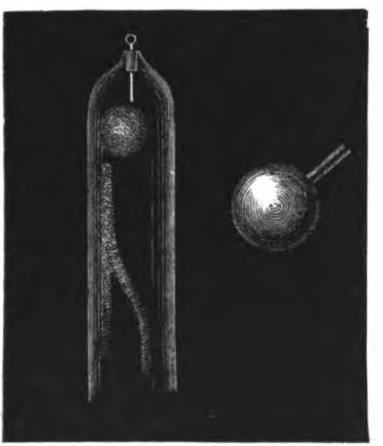


Fig. 205.—Repulsion of Glow by a Conductor.

Fig. 206.—Henry's Comet.

Newton, Olbers, Bossel, Faye, Plana, and others. Although there is no doubt whatever about the repulsion, as yet we are not able to bring forward a satisfactory explanation of its cause. Nobanitzky and Reitlinger think the force of repulsion between the sun and the comet's tail explained by their experiment, shown in Fig. 204, which was verified by a series of other experiments.

Application to Incandescent Lamps.—From a mere theoretical point of view, Crookes' experiments on electrical phenomena in rarefied spaces, and his deductions therefrom, claim attention; but they are of more importance from a practical point of view, because of the daily increasing use of incandescent lamps. Here we have conductors through which currents pass in an imperfectly insulating medium. It follows that the difference of potential in the conductor must bring about side discharges between the different parts of the conductor, and this occurs the sooner, the higher the tension of the currents. By making use of alternating currents of 200 to 230 volts, the blue glow was observed by Puluj at the platinum wires to which the carbon filament was fastened. This glow light underwent the same changes on further exhaustion as are observed

in Giessler's tubes. At a pressure from 1 to $\frac{1}{2}$ millimetre, the glow light surrounded the wires. For a distance of about 2 to 3 millimetres, at a pressure of 0·07 millimetre, the glow light filled the whole glass bulb. As alternating currents were used, the glow light, of course, appeared at both platinum wires. The incandescent carbon filament, however, showed no sign of glow light.

Wächter proved the existence of material particles in the spark, and the disgregation of electrodes, etc., and Puluj has shown that material particles are also carried away by the current from both conductor and electrodes; a similar mechanical disgregation was to be expected in the carbon filament also, and has been proved to exist by Puluj. This experiment showed that dissipation takes place along the whole surface of the filament, but is more marked at the

Fig. 207.—Carbon Filament of Incandescent Lamp.

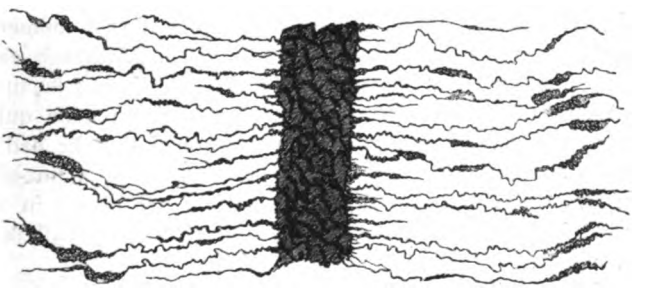


Fig. 208.—Magnified Diagram of Carbon Filament.

negative than at the positive pole; it follows that a filament must wear out the sooner when its resistance is considerable and the current has a high tension. Currents of high tension are not economical, for this reason, that they favour the blue glow; the whole electrical energy which is necessary for the production of it is lost for the light effect, and only serves to heat the glass globe.

In order to obtain greater resistance in the carbon filament of the incandescent lamp, Maxim and others adopted the plan of making the filament incandescent in an atmosphere of carburetted hydrogen, which is decomposed by the current, the carbon being deposited on the carbon filament. Puluj describes the phenomenon during carbonisation in the following manner: The carburetted hydrogen atmosphere is heated to such an extent that decomposition takes place in consequence of the high temperature, causing black clouds of smoke and deposition of soot. Besides this decomposition of the gas molecules by heat, they are farther separated by an electrolytic process, which is brought about by the electrical discharges between the separate portions of the carbon filament. The carbon of the carburetted hydrogen is deposited according to the direction of the current. Fig. 207 represents the carbon filament with its deposit in its natural size. Fig. 208 shows the same eighty times magnified.

ANIMAL ELECTRICITY.

Physiological Effects.—Discharges of electricity through the limbs produce somewhat painful sensations in the nervous system, and cause the muscles to contract. The discharge from an electric machine producing high potential, or from a condenser or an induction coil, gives a sharp shock. The current from a battery of a few Grove cells passing through the system produces a tingling sensation, which is considerably increased if the circuit be quickly "made" and "broken."

The effect of these interruptions of the current may easily be seen in a frog's leg. On break and make of the current, motions in the frog's leg are observed, but it is perfectly at rest when a uniform current is sent through it. Du Bois-Reymond thus states the law for electrical effects upon nerves: It is not the absolute value of the E. M. F. of the current at each moment that causes motion in the nerve, but the change of this value. Although electrical currents only influence nerves at make and break, and during fluctuation of the current, a uniform flowing current, however, does not remain quite without influence upon the nervous system. Volta mentioned that he had a peculiar sensation when he passed the current of 100 elements of a zinc-silver pile through his body. When the wires of a large battery are placed in the ears a continued noise is heard. A feeble current through the eye-ball produces the sensation of a flash.

The sensitiveness of a frog's leg is so great for alterations in the current that it may be considered the most sensitive electroscope. The very feeble currents of a telephone, for instance, are sufficient to affect it. If, therefore, the freshly exposed nerves of a frog be connected with the wires of a telephone, the muscle will move with different rates of rapidity as different words are spoken to the telephone. Experiments by Nobili and Matteucci have shown that when the nerve and muscle of a frog are connected by a water contact with a delicate galvanometer, a current manifests itself. This has been called the muscle current. Du Bois-Reymond has shown that the ends and sides of a freshly cut muscle have a difference of potential. He used for these experiments a very sensitive multiplier (with 4,600 turns), and attached to the wire terminals platinum plates, which were immersed in vessels containing concentrated solutions of ordinary salt. When only the demonstration of the existence of a muscle current was

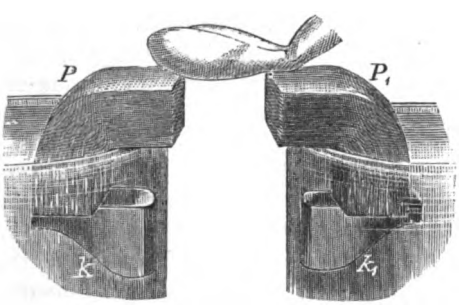


Fig. 209.—Current of a Muscle.

intended, it was sufficient to merely connect the two glass vessels with each other by means of the animal's limb; as, however, the concentrated salt solution is liable to affect the animal tissue, and so interfere with the continued action, he connected in another manner the two vessels containing the salt solutions. Well-varnished wood blocks K K_1 were used, as shown in Fig. 209, and upon them were placed blotting-pads which had been thoroughly soaked in the albumen of eggs. Upon these the animal's limb was laid, and so every contact with the salt solution avoided. Before, however, the experiment commenced, a third layer of blotting-paper was laid across the two pads K and K_1, for the purpose of neutralising any polarisation that might exist between the platinum plates in the salt solution. When this has been done, and the needle points to zero, the muscle under examination is placed upon P and P_1, with the precautions mentioned. A violent deflection of the needle indicates a current which becomes considerably

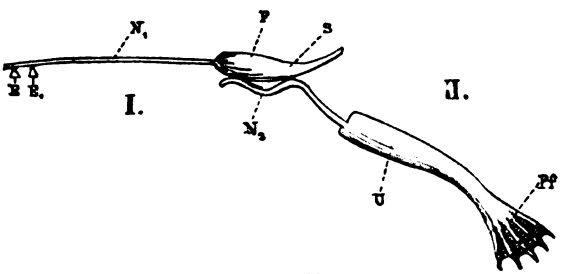


Fig. 210.—Current in Nerve and Muscle.

weaker when the muscle is left in its position. If now the muscle be removed, and circuit made with soaked blotting-paper, the needle shows a deflection in the opposite direction; this current is due to the polarisation of the platinum plates by the muscle current. The direction of the muscle current depends upon the part of the animal's limb from which the muscle is taken. With regard to the duration of the muscle current, Matteucci's investigations showed that the current decreases in the first ten minutes after the separation of the limb from the body of the animal; then remains more or less steady for the next five or six hours. A very interesting phenomenon was first observed by Matteucci, but not correctly explained, in what are called secondary motions. Du Bois-Reymond showed that these depend upon the effect of the current circulating in the nerve or muscle when at rest. They may be shown experimentally as follows: Nerve N_1 (Fig. 210) is so prepared that it lies exposed, as represented in the figure, while N_2 is partly exposed. I and II are now brought together in such a manner that the nerve of II touches the muscle of I at two different places, viz. the red muscle flesh at F and the sinew at S. In this position the nerve piece at N forms a circuit for the muscle current F S. If now the nerve N_1 be excited in any manner, say by a sharp cut, not only will the muscle F S move, but also the portion at U, although U is in no manner anatomically connected with N_1. The

explanation of the phenomenon is as follows: II acts as a very sensitive electroscope to measure the muscle current generated by F S, but the current decreases on account of the contraction of the muscle. This alteration of the current was manifest at U P*f* through N_2. When the nerve N_1 is placed over the wire ends E E_1 of an induction coil which is in action, nerve N_1 is not affected once only by a cut, as formerly, but moves several times in rapid succession. The muscle F S must have become permanently contracted. This continued contraction resembles *tetanus*, and consequently the muscle is said to have become tetanised. The induced currents here follow so quickly upon each other that the muscle has no time to return to the normal position. Every motion in I causes a motion also in II; it follows that tetanism in I causes also tetanism in II. If a galvanometer be substituted for II, it may be proved directly that the secondary motions are due to a sudden decrease in the muscle current. Du Bois-Reymond also proved that the contraction of muscles produced currents. By using a sensitive galvanometer, he proved that the sudden contraction of the muscles of the arm produced a current.

Organisms producing Electrical Discharges.—It has been known for centuries that certain animals, such as the Raia torpedo, or electric ray, and the Gymnotus electricus, or electric eel, are capable of giving powerful electric shocks. It seems that the Abyssinians used the electric eel as a remedy for nervous diseases. The torpedo, or electric ray, of the Arabians, reaches a length of from 15 to 24 inches. It was found in the Nile by Forskal, and in the Senegal by Adanson. According to Boehm, the electrical organ of the ray consists of a thin network of six or more layers, which runs along between the skin and muscles; this apparatus is fed and regulated by a nerve consisting of many branches. This network is supposed to possess healing properties.

From a great variety of experiments on this fish, Mr. Todd drew the following conclusions:

1. That the electrical discharge is a vital action dependent on the life of the animal.

2. That the action of the electrical organs is entirely voluntary.

3. That frequent action of them is injurious to its life, and, if continued, deprives the animal of it.

4. That when the nerves and the organs are cut, the torpedo loses the power of giving a shock, though it appears more vivacious, and lives longer than those in which this change has not been produced, and in which the electrical power is exerted.

5. That the possession of one organ only is sufficient to produce the shock.

6. That the perfect state of all the nerves of the electrical organs is not necessary to the production of the shock.

7. That (as was shown by Dr. Hunter) a more intimate relation exists between the nervous system and electrical organs of the torpedo, both as to structure and functions, than between the same and any organs of any kind of animal with which we are acquainted.

Dr. Williamson, of Philadelphia, thus sums up the results of his observations upon the gymnotus.

1. When the gymnotus is touched by the hand a shock is felt in the fingers, and often as far up as the wrist and elbow; and when it is touched with an iron rod twelve inches long, the shock is felt in the finger and thumb.

2. If the eel is provoked by one person, the hand of another person held in the water will experience a shock.

3. When the eel was touched and provoked with one hand, and the other held in the water at a small distance, a shock passed through both arms; and the same effect was produced when the hand held a wet stick in the water; and when the same experiment was made by eight or ten persons who joined hands a shock was also experienced.

4. When the first of eight persons pinched the tail while the last touched the head, they all experienced a severe shock.

5. The shock of the eel was found to pass through those substances which are conductors, and to be stopped by those which are non-conductors, of electricity.

6. An insulated person electrified exhibited no marks of electricity, and pith-balls refused to diverge either when suspended over the eel's back or touched by an insulated person when he received the shock.

7. Dr. Williamson succeeded in making electricity of the eel pass through a small space of air, and exhibit the electric spark when the fish was in the open air. But the spark is not visible when the fish is placed in water.

The method of fishing for the electric eels by horses, as described by Humboldt, is most interesting. The Indians forced thirty horses to enter a pool of muddy water surrounded with fir trees. "The extraordinary noise caused by the horses' hoofs makes the fish issue from the mud, and excites them to combat. These yellowish and livid eels, resembling large aquatic serpents, swim on the surface of the water, and crowd under the bellies of the horses and mules. A contest between animals of so different an organisation is a striking spectacle. The eel presses itself against the belly of the horse, and makes a discharge along the whole extent of its electrical organ. The horses were stunned, and two were drowned from their inability to rise. The wearied gymnoti at last dispersed, and were easily harpooned by the Indians."

More powerful shocks are given by the electrical or Surinam eel, described first by A. Humboldt and then by Sachs. The electrical eel attains a length of two yards or more, and weighs from 30 to 50 lbs. The skin of the animal (at the upper side olive green, lower side orange red) is continually coated with a slime, which, as Volta says, conducts electricity twenty to thirty times better than water. About four-fifths of the whole body, says Boehm, is taken up by the electric organs, four in number; they consist of a yellow-reddish gelatinous matter arranged in bundles, which again consist of horizontally placed plates, divided by longitudinal skins into cells.

Balon touched an electric eel carelessly without feeling anything; but when

he placed his finger on the back, he felt little shocks. The same fish fell accidentally to the ground, and as none of the negroes were inclined to touch the eel, Balon himself caught hold of its tail; he then received a shock so violent as almost to throw him to the ground. He felt very strange sensations in the head for a considerable time after.

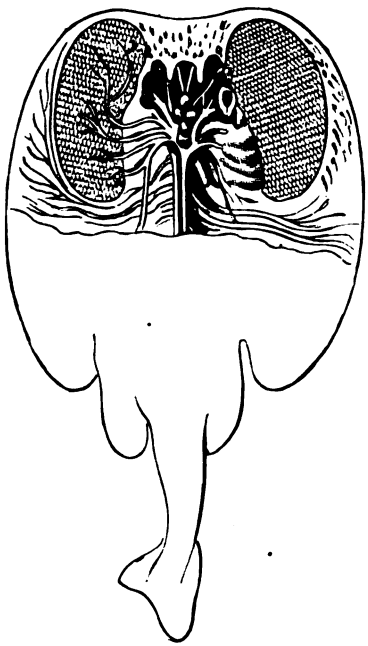


Fig. 211.—The Electric Ray or Torpedo.

The electrical ray has been examined by Redi, Réamur, Bancroft, Humboldt, Geoffroy, and others. The electric organ lies between head, gills, and breast fins, as shown in Fig. 211. It consists of cells arranged similarly to those of the honeycombs of bees; these cells are separated from each other by fine layers of skin, and are animated by a system of nerves. The effect of the shocks is less powerful than those of an electric eel, but still is painful. The effects are more powerful under water, and the greater the extent of surface touched. The animal is capable of giving shocks at pleasure, and will give a series of shocks when irritated. The largest variety is met with as much as four feet long, and weighing 60 or 70 lbs.

With regard to the effects of the electrical organs in the three fishes, two theories are advanced. Du Bois-Reymond considers the electric organ an apparatus similar to a galvanic battery, and thinks the nerves running along it influence the apparatus only indirectly, their function being to communicate the will of the animal. The generation of the electrical currents is supposed to take place in the organ itself like the muscle current in the muscle. The French physicist, Ranvier, thinks the electric organ only a secondary apparatus, resembling our secondary batteries; electrical currents are supposed to be generated in the brain, and then to flow over to the apparatus, where they cause chemical action. This charging operation is executed when the animal is at rest. If now it wishes to give a shock, by means of the nerve system it arranges in series the secondary elements which have been during rest parallel, and thus causes discharge.

APPENDIX TO PART I.

IT will be an assistance to the reader if we here collect the laws previously explained, and state additional facts with regard to measurements which will be made use of in the subsequent portion of the work.

The laws of electricity have been made to furnish a connected system of units depending on the units of length, mass, and time. Such units are said to be *derived* from the fundamental units.

Suppose, for instance, that we use the English system based on the foot, pound, and second.

The foot and the second give us the units of velocity and acceleration. A velocity whose measure is 1, is 1 ft. per second; and an acceleration whose measure is 1, is a gain of velocity equal to 1 ft. per second in a second.

Forces are measured by the velocity they generate per second in the unit of mass. A force whose measure is 1, is therefore a force that generates in 1 lb. of mass a velocity of 1 ft. per second in a second. What is the magnitude of such a force? We may answer the question by the following consideration: The acceleration of a falling body is about 32·2 feet in a second. Hence the weight of a pound when acting on the mass of a pound would give the mass a velocity of 32·2 ft. per second in a second. The measure of such a force is therefore 32·2. It contains, therefore, 32·2 units of force. Hence the unit of force is $\frac{1}{32 \cdot 2}$ of the weight of a pound (a little less than the weight of half an ounce).

If we use the French decimal system, the units of length and mass are the centimetre and gramme. The acceleration produced by gravity at Paris is 981 centimetres per second in a second. The weight of a gramme gives to the mass of a gramme a velocity of 981 centimetres per second in a second. Hence in this system the measure of the weight is 981 units of force. The unit of force is therefore $\frac{1}{981}$ of the weight of a gramme. This unit of force is that used in scientific investigations, and has therefore received a name of its own. It is called a *dyne*. There are 981 dynes in the weight of a gramme, and as one pound is 453·593 grammes, there are 453·593 × 981, or 444,975 dynes in the weight of a pound. It is frequently convenient to use the weight of a pound as a unit of force, and to distinguish such units as are adopted for practical purposes from the units found by a consideration of the scientific relationships; we call the former *practical units*, and the latter *absolute units*. The characteristic of the absolute units is that they are readily derivable from the three fundamental units. The system of absolute units is therefore one that is independent of all other arbitrary quantities excepting the three fundamental units of time, length, and mass. An absolute system, in which the centimetre, gramme, and second are the fundamental units, is generally described as the C. G. S. system.

Work.—The work done in overcoming a resistance equal to the weight of a pound through a distance of one foot is a practical unit of work called a *foot-pound.* A force of a dyne acting through the distance of a centimetre is the absolute unit of work called an ERG.

A horse-power is a rate of working, being 33,000 foot-pounds a minute = 550 foot-pounds per second = 7,460 million ergs per second, or 74,600 kilogramme-metres per second. The absolute unit of rate of working is the *watt*, which is ten million ergs per second.

Hence one horse-power = 76 watts.

Magnetic Units.—We will next proceed to define two units used in magnetic measurements, namely, those of a magnetic pole and a magnetic field.

(*a*) *Definition of Strength of Pole.*—The strengths of two magnetic poles are proportional to the forces with which they will repel a given pole placed in succession at the same distance from them.

Like poles repel, unlike poles attract, and the force exerted between two magnetic poles varies inversely as the square of their distance. Hence if F be the force and m_1 m_2 the measures of the strengths of two poles in terms of any unit, and if d be the distance between the poles, then the simplest expression of the above law is

$$F = \frac{m_1 m_2}{d^2}.$$

If d be a centimetre, and the force exerted be one dyne, and if in addition m_1 and m_2 are equal to one another, then each pole will be one of unit strength in the absolute or C. G. S. system. In other words, that magnetic pole is of unit strength that repels a pole of equal strength placed at a distance of one centimetre with a force of one dyne.

(*b*) *Definition of Magnetic Field.*—The influence of any magnet extends all round it, so that if at any point the pole of a smaller magnet were placed, it would experience a force varying with its distance from the larger magnet. The fact that the magnetic influence pervades a space is expressed by saying that the space is a *magnetic field*, the strength of the force that would be exerted on a magnetic pole at any point being called the *intensity of the field.* Hence the intensity of the field at any point is measured by the force with which it acts on a unit magnetic pole placed at that point. In absolute measure, therefore, the unit of intensity is that at which a unit pole is acted on by the force of a dyne. If F be the force acting on a pole of p units, where the intensity of the field is H, then

$$F = p\,H.$$

Systems of Electric Units.—There are two routes by which we may establish a system of electric units, the starting point of the first being the law of attraction of two small spheres charged with electricity, and that of the second being the law of attraction between two magnetic poles. The first course gives a series of units called the *electro-static system*, the second leads to a series called the *electro-magnetic system.*

The Electro-static System of Units.—The order in which the units are determined in this system is as follows: (*a*) Quantity, (*b*) current, (*c*) difference of potential, (*d*) resistance, (*e*) capacity.

(*a*) If q_1 and q_2 be two quantities of electricity measured in terms of any unit, and d be the distance between them, the force F with which they attract or repel each other is proportional to $\frac{q_1 q_2}{d^2}$, and the simplest expression of the law is $F = \frac{q_1 q_2}{d^2}$.

Hence, by making $F = 1$, $d = 1$, and $q_1 = q_2$, we see that a unit of quantity is that quantity of electricity which when placed at a distance of a centimetre from an equal quantity of like kind repels it with a force of one dyne.

(*b*) When a quantity of electricity Q is discharged at a uniform rate along a wire, the quantity that flows per second is termed the strength of the current. Hence if C be the strength of current when a quantity Q flows in t seconds,

$$Q = C\,t.$$

Hence the unit of quantity gives us a unit current as the current which discharges a unit of quantity in a second.

(*c*) By means of the analogy between a difference of level and a difference of potential, we illustrated the fact that if C be the weight of a quantity of water, and E the height from which it falls, then the work that may be done by this quantity is measured by the product C E; and similarly if C be a quantity of electricity flowing in a second between points having a difference of potential E, and if W be the work done by the current between these points in a second,

$$W = C\,E.$$

If we make $W = 1$ and $C = 1$, this gives us the unit difference of potential. Hence there is a unit D P between two points when one erg of work is required to convey a unit of electricity from one point to the other.

(*d*) Ohm's law connects current, difference of potential, and resistance; hence with *b* and *c* it gives the unit of resistance as that through which a unit D P produces a unit current.

(*e*) Similarly that conductor has a unit of capacity which is raised through a unit D P by a charge of one unit of quantity.

Electro-magnetic System of Units.—The order in which the units are determined in this system is as follows: (*a*) Unit pole, (*b*) current, (*c*) quantity, (*d*) electromotive force, (*e*) resistance, (*f*) capacity.

(*a*) We have already defined the unit pole. The theory of the tangent galvanometer supples us with the next step.

(*b*) If two magnetic poles p_1 p_2 act on each other at a distance d, and if F be the force exerted between them, then we have seen that

$$F = \frac{p_1\,p_2}{d^2}.$$

If now one of these poles, instead of being acted on by another magnet, is acted on by a current C passing through a portion of a circuit in the arc of a circle of radius d, the pole p_1 being in the centre, the force is still represented by the equation

$$F = \frac{p_1\,p_2}{d^2};$$

but p_2 in this case is a quantity varying with the current, and also with the length of the circuit in the circle. If the length of this arc be a,

$$\text{then } F = \frac{p_1\,(Ca)}{d^2} \quad \text{or } C = \frac{F\,d^2}{p_1\,a}.$$

When we have determined the unit pole and the dyne or unit force, we can make each quantity in this equation unity, and hence obtain the unit current. Hence a

current has unit strength when one centimetre of its circuit bent into an arc of one centimetre radius exerts a force of a dyne on a unit magnetic pole placed at the centre.

(*c*) The unit of quantity is, then, that quantity which is conveyed by unit current in a second.

(*d*) The unit difference of potential, or the unit electromotive force, is now obtained by the consideration of the work W done per second in consequence of the flow of a current C between two points whose D P is E.

$$W = C E.$$

Hence a unit D P or unit E. M. F. exists between two points when the flow of a unit current between these points produces a unit of work or energy in a second. By inverting this definition, and considering the current as produced at the expense of energy, we may take the statement thus : A unit D P exists between two points when the expenditure of an erg of work a second produces a unit current or conveys a unit of positive electricity from one point to the other.

(*e*) By next considering Ohm's law, we have the unit of resistance. Since $C = \frac{E}{R}$, we see that the unit of resistance is that of a conductor in which a unit electromotive force between the ends causes in it a unit current.

We may transpose the last two steps thus : for t seconds

$$W = C^2 R t.$$

Hence the unit of resistance is that of a conductor in which a unit current generates a unit of energy (or does a unit of work) in a second of time.

Since $C = \frac{E}{R}$, the unit of electromotive force is that which produces a unit current in a conductor of unit resistance.

It must be borne in mind that there is a wide difference between the units of the two systems. For instance, the capacity of a sphere which would have the distance of the earth from the sun would be but one-millionth part of the electro-magnetic unit, whereas the capacity of an orange would be more than ten times the electrostatical unit, but the unit of resistance in the first system is as many millions of times *smaller* than that of the second system, as the unit of capacity of the first is *larger* than that of the second.

The practical units based on the electro-magnetic system have been so chosen that the fundamental laws may hold with regard to them as they do with regard to the absolute units. For example :

A coulomb is the quantity conveyed in a current of one ampere a second.

The coulomb changes a body having a capacity of one farad to a potential of one volt.

A volt is the E. M. F. which maintains a current of one ampere whose resistance is an ohm.

The relation of the practical units is further shown by the following table :

TABLE OF PRACTICAL UNITS.—ELECTRO-MAGNETIC MEASURE.

No.	Unit.	Symbol.	Name.	Relation to other Units.	Derivation.	Value.	
						C.G.S.	Equivalents.
1	Current	C	Ampere	Volt ÷ ohm	From Unit pole and Tang. Galv.	10^{-1}	·0000105 gramme of hydrogen liberated per second.
2	Quantity	Q	Coulomb	Ampere per second	From 1.	10^{-1}	
3	E. M. F.	E	Volt	Ampere × volt	From Unit of Work and 1.	10^{8}	·926 standard Daniell cell.
4	Resistance	R	Ohm	Volt ÷ ampere	From 1 & 3, by Ohm's Law.	10^{9}	106 cm. mercury, 1 sq. mm. section at 0° cent.
5	Capacity	K	Farad	Coulomb ÷ volt	From 2 & 3.	10^{-9}	
6	„	„	Microfarad	1 millionth farad	5	10^{-15}	2·5 knots of D.U.S. cable.
7	Power	H P	Watt	Volt × ampere	—	10^{7}	·0013405 of $\frac{1}{746}$ horse-power.
8	Work	W	Joule	Volt × coulomb	—	„	·7373 foot-lbs.
9	Heat			Amp.^{2} × sec. × ohm	—	„	·238 caloric, or ·238 of the heat required to raise a gramme of water 1° centigrade.

Connection of Heat and Electricity.—Work and heat are connected by a multiplier, called Joule's equivalent of heat. We have already seen (page 192) that if work be measured in foot-pounds, and heat in terms of a unit which is the amount of heat required to raise the temperature of 1 lb. of water 1° F., then the work W and the heat H, which is equivalent to it, are connected.

$$W = 772\ H$$
$$\text{or } W = J\ H.$$

The number represented by J will differ with every change of unit. If the work be in ergs, and heat in units, each of which would raise the temperature of 1 gramme of water 1° C. (gramme-centigrade units), then

$$J = 42 \times 10^6.$$

A current C through a resistance R for t seconds does work W such that

$$W = C^2 R t.$$

If the work be changed to heat H,

$$W = J H = C^2 R t.$$
$$\text{Hence } H = C^2 R t \div (42 \times 10^6)$$
$$= (10\ C)^2 \left(\frac{R}{10^9}\right) t \div 4.2$$
$$= (C^2 \text{ amperes})\ (R \text{ ohms})\ t \div 4{\cdot}2.$$

Hence a current of one ampere through one ohm generates $\frac{1}{4\cdot2}$ (= ·24) heat units a second.

Unit of Illuminating Power.—The experiences connected with electric lighting have associated units of work, electricity, and light. A practical unit of light

has been introduced, and called a *candle-power*, which is the amount of light given by a sperm candle weighing one-sixth of a pound, and burning one hundred and twenty grains an hour.

The French unit of light, or Bec-Carcel, is the light of a Carcel lamp burning 42 grammes of pure colza oil per hour, with a flame 40 m. high. It is 9·5 British standard candles, and is 7·6 of the unit candles used by the Germans. The Congress suggested as the unit of light that which is emitted by a square centimetre of molten platinum, but there are almost insuperable difficulties in the way of fixing such a unit.

CONVERSION TABLE OF FRENCH AND ENGLISH MEASURES.

One metre = 3·28 ft. = 3 ft. $3\frac{3}{8}$ in. = 40 inches nearly.
One centimetre (·01 metre) = ·4 inches nearly.
One inch is about $2\frac{1}{2}$ centimetres (exactly 2·54).
One yard is $\frac{11}{12}$ of a metre, or 11 metres are equal to 12 yards.
To convert metres or parts of metres into yards, add $\frac{1}{11}$.
To convert metres into inches, multiply by 40.
To convert inches into metres, divide by 40.
One litre is about $1\frac{3}{4}$ pint (it is 0·57 per cent. more).
One gallon contains above $4\frac{1}{2}$ litres (it holds about 1 per cent. more).
One kilolitre (a cubic metre) holds nearly a ton of water at 62° Fahr.
One kilogramme is about $2\frac{1}{5}$ lbs. (about $\frac{1}{4}$ per cent. more).
One thousand kilogrammes, or a metric ton, is nearly one English ton (about $1\frac{1}{4}$ per cent. less).
One hundredweight is nearly 51 kilogrammes ($\frac{3}{8}$ per cent. less).
One kilogrammetre is 7·233 foot-pounds.
One foot-pound = ·138 kilogrammetre.

PART II.

The Technology of Electricity.

DIVISION I.

GENERATION AND CONDUCTION OF ELECTRICITY.

DIVISION II.

PRACTICAL APPLICATIONS OF ELECTRICITY.

PART II.

The Technology of Electricity.

DIVISION I.

GENERATION AND CONDUCTION OF ELECTRICITY.

HISTORY OF ELECTRIC MACHINES.

The First Magneto-Electric Machine.—The discovery of induction by Faraday, in 1831, gave rise to the construction of magneto-electro machines. The first of such machines that was ever made was probably a machine that never came into practical use, the description of which was given in a letter, signed "P.M.," and directed to Faraday, published in the *Philosophical Magazine* of 2nd August, 1832. We learn from this description that the essential parts of this machine were six horse-shoe magnets attached to a disc, which rotated in front of six coils of wire wound on bobbins.

Pixii's Machine.—Pixii, 3rd September, 1832, constructed a machine, the principle of which will be understood from Fig. 212. N S is a powerful steel magnet, made to rotate under the fixed soft iron cores *a b*. The rotation of S N causes currents to be induced that change twice in each complete revolution, viz., when S is opposite *b*, and N opposite *a*, and when S is opposite *a*, and N opposite *b*.

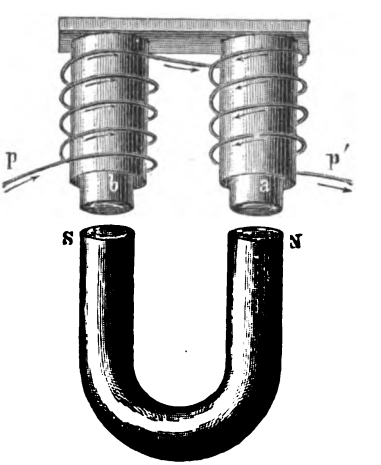


Fig. 212.—The Principle of Pixii's Machine.

We may trace the effect produced in three ways: (1) We may apply Ampère's rule for magnetic currents and their attractions; (2) we may apply Lenz's law simply; (3) we may use Maxwell's rule. Let us trace the effect produced when S approaches *b*, and N approaches *a*, by the first of these methods. The mass of soft iron *a b* becomes magnetised by induction as S N approaches it, so that its north pole is nearest S, and south pole nearest N. The effect is therefore the same as would arise on the sudden introduction of

a magnet into the coil surrounding A B. The sudden appearance of this magnet in the coil would, as we have seen, induce a current in the wire forming the coil.

The directions of the induced currents are shown in the figure by arrows. In s and *b*, as s approaches *b*, the magnetic current is anti-clockwise; in the coil *p* surrounding *b* the electric current is therefore clockwise. But as s approaches *b* on the one side, the north pole of the magnet also approaches *a* on the other side. The magnetic currents in the magnet N flow clockwise, hence the induced magnetic currents in the core *a* flow clockwise, and the induced electric current in the electric coil *p'* circulates against the hands of a clock. If the currents be followed through the turns of the coil *p p'*, we find that in consequence of the mode of winding it does not change its direction at all: although at *p* it flows with the hands, and at *p'* against the hands, of a watch. As the magnet continues to move, s leaves *b* and approaches *a*, while N leaves *a* and approaches *b*. If we now follow the directions of the currents, we find that they flow in exactly opposite directions to those in which they flow during the first half-turn of the magnet: it follows that the directions of the induced currents must change twice in the coil for every revolution of the magnet.

The result is in accordance with Lenz's law: that is to say, the induced currents in the coil are such as will resist the motion. As s approaches *a*, then, the pole of the coil at *a* must repel s, and must therefore be a similar pole to s; but as s leaves *a*, the pole of the coil at *a* must attract s to resist the motion, and must therefore be a dissimilar pole. This gives in *a* currents clockwise as s approaches, anti-clockwise as s recedes.

Pixii's Commutator.—As the continued alterations in the direction of the currents might be inconvenient for many purposes, Pixii added a commutator to this machine, which causes the currents in the outer circuit to flow in one and the same direction. Fig. 213 represents the commutator in plan. The axis of rotation of the horse-shoe magnet carries a cylinder made of insulating material fitting into a hollow cylinder of metal, irregularly divided by an insulating layer into two parts M_1 and M_2. Two metal springs F_1 and F_2 conduct the induced currents of the coil s into the commutator. Two other springs f_1 and f_2 conduct the currents from the commutator into the outer circuit. During rotation the four springs slide along the surface of the cylinder. We may observe that F_1 and F_2 slide over the same portion of the cylinder, whilst f_1 and f_2 have to pass over the insulating strips. If the springs are properly adjusted they will pass the insulating layer—that is, will change metals—exactly at the instant when the direction of the current changes in the

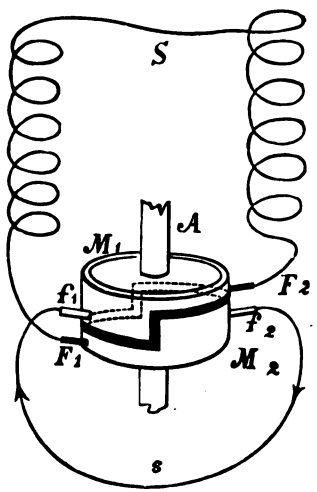


Fig. 213.—Pixii's Commutator.

coil. We have seen that the direction of the currents changes twice for every complete revolution of the horse-shoe magnet. The springs f_1 and f_2 will therefore for every revolution of the cylinder pass the insulating layer twice. The springs f_1 f_2 will slide from one portion of the metal cylinder to the other at the instant when the change of direction in the currents takes place. The

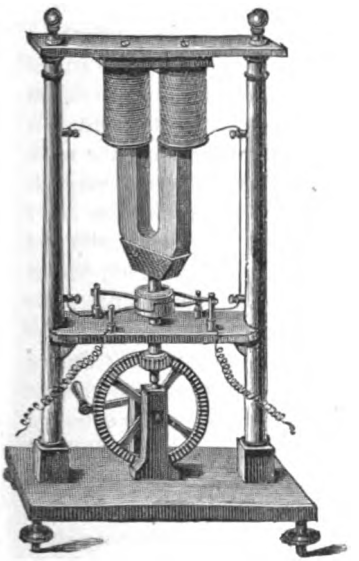


Fig. 214.—Pixii's Machine.

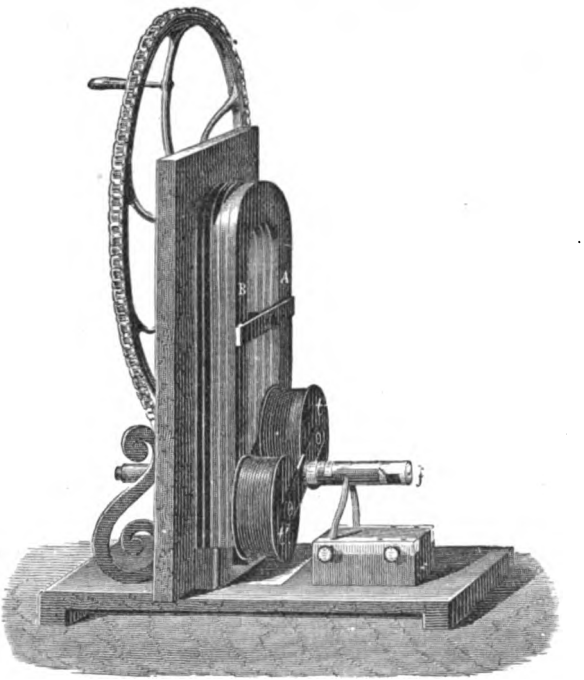


Fig. 215.—Clarke's Machine.

result of this double change at the same instant is a uniform direction of the currents in the circuit s.

Fig. 214 shows how the different parts of the machine constructed by Pixii were arranged. The great drawback to the usefulness of this machine was, that the heavy iron matter of the magnet had to be made to rotate, which must have caused considerable difficulty with machines of great dimensions.

Ritchie's, Clarke's, and Siemens' Improvements.—Almost at the same time, Ritchie, Saxton, and Clarke constructed similar machines. Clarke's is the best known, and is still popular in the small and portable "medical" machines so commonly sold. Its construction is as follows:—In front of a powerful horse-shoe magnet A B, there are two bobbins t and t', of insulated wire. These two bobbins have soft iron cores, connected by a soft iron cross piece $o\,o$ so as to form a horse-shoe magnet, which rotates round

a horizontal axis *f*, being driven by the pulley behind the magnet A B. The two coils of wire are continuous, so that a single current may flow round both; but they are so joined that the current flows in a right-handed direction round one, and in a left-handed direction round the other. While two ends of the wire on *t* and *t'* are directly joined, the two other ends are connected through a set of springs rubbing on suitable contact pieces on the axis *f*, with two fixed terminals, and the circuit is not complete till these are joined. We will suppose this to be done. As the coils rotate, each soft iron core is successively magnetised in opposite directions; thus coil *t*, when opposite a north pole, has its south pole near the magnet and its north pole at the back, and this arrangement of the magnetism is reversed when *t* is opposite the south pole; thus, in every revolution a magnet is, as it were, introduced into *t*, withdrawn, replaced with its poles in the opposite direction, and again withdrawn. The withdrawal of a magnet having its north pole at one end of *t*, and the introduction of a magnet having its south pole at the same end, both tend to induce a current in one direction; but the withdrawal of this second magnet, and the introduction of the reversed magnet, induce a current in the opposite direction. Thus from the instant the coil *t* begins to leave the south pole, to that instant at which it arrives opposite the north pole, a current in one and the same direction is being induced; but as soon as *t* begins to leave the north pole and return to the south pole, the direction of the current is reversed, and continues reversed until opposite the south pole. Thus two equal and opposite currents are induced in *t* during each revolution. The same statements hold good of *t'*, but when the current induced in *t* is right-handed, that in *t'* will be left-handed. When the coils are joined as described, the two currents are added to one another. Without special provision the currents would be reversed between the terminals at every half-revolution; but the commutator on the axis *f*, already described, arranges that although the currents must necessarily be reversed in the coils, they shall flow always in one direction between the terminals. The currents between the terminals must, however, rise to a maximum and decrease to a minimum once during each half-revolution. The maximum currents occur at those points where the armature (as the soft iron continuous core is termed) resists the motion most strongly. At these points the greatest change of magnetism is taking place in the armature.

The motion of the coils alone, without a core, would give rise to similar currents, as explained in the earlier pages of this work. But these currents would be much weaker than when iron cores are employed.

Fig. 216 represents a larger machine, constructed by Stöhrer (1843), on the same plan as Clarke's, but with six coils instead of two, and three compound magnets instead of one. The six coils rotate very quickly immediately over the poles of the very powerful compound permanent magnets. The wire on the bobbins is so arranged that when the coils approach the magnets currents in one direction are generated, and when the coils move away from the magnets currents in the other direction are generated, so that the

sum of the currents produced by approaching the magnetic poles flows in opposite direction to the sum of the currents produced by receding from the magnetic poles. By using the commutator *a b c d* the two series of currents are made to flow in the same direction at *e f*. The machines constructed by Nollet (1849) and Shephard (1856) had still more magnets and coils. Shephard's machine was modified by Van Malderen, and was called the Alliance machine (see p. 244).

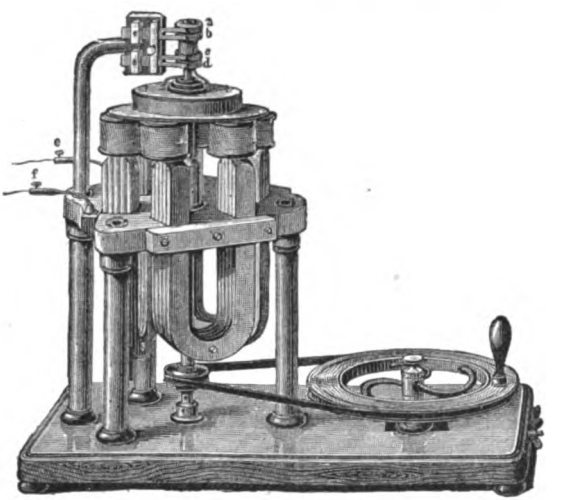


Fig. 216.—Stöhrer's Machine.

Dr. Werner Siemens, while considering how the inducing effect of the magnet can be most thoroughly utilised, and how to arrange the coils in the most efficient manner for this purpose, was led in 1857 to devise the cylindrical armature. By this arrangement the coils are made to revolve in the most powerful part of the magnetic field. In its simplest form Siemens' armature consists of an iron cylinder which is cut (as shown in Fig. 217; *a*) so that its cross section is of the form I. Covered copper wire is wound longitudinally round the cylinder thus prepared (Fig. 217; *b*). The horse-shoe magnets are placed parallel to each other, and cut out at their poles N S, so that the cylindrical armature may move in the hollow space (Fig. 217; *c*). By this arrangement the coils are exposed to the most powerful magnetic effect, and, to use the language of Faraday, they cut the greatest number of lines of force in the most powerful part of the magnetic field. Fig. 218 represents a small Siemens machine, by means of which more powerful currents were

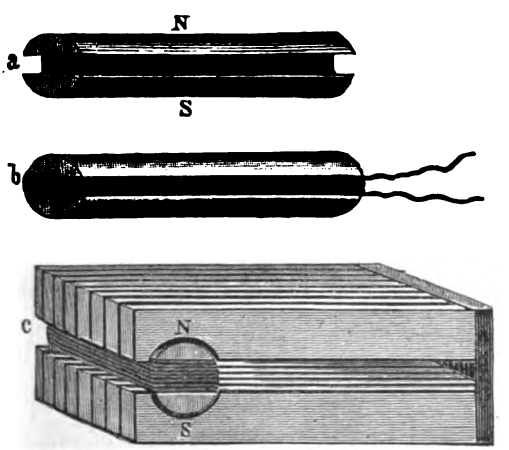


Fig. 217.—Siemens' Cylindrical Armature.

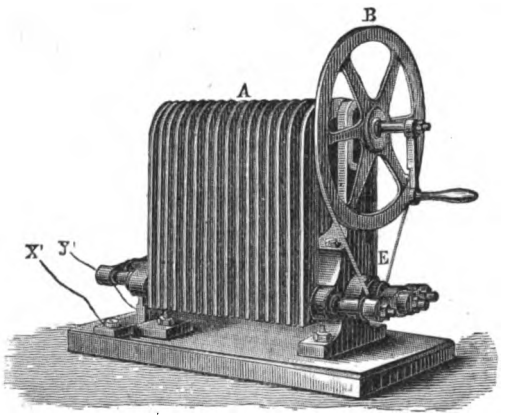


Fig. 218.—An Early Siemens Machine.

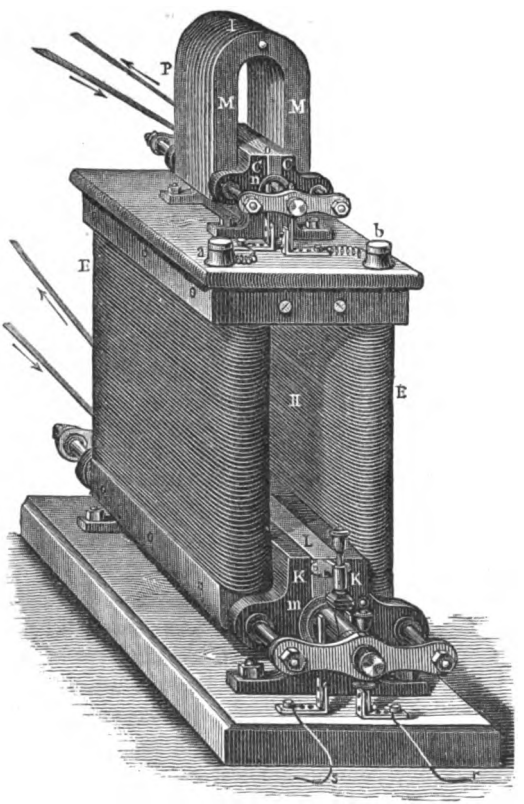


Fig. 219.—Wilde's Machine.

generated than by the earlier machines already described. A are the steel magnets placed vertically. The cylindrical armature is seen at E. It is made to rotate rapidly by means of the multiplying wheel B; *x y* are the wires through which the induced currents are conducted into the outer circuit.

The Introduction of Electro-Magnets by Sinsteden, Wilde, and others.—Sinsteden in 1851 pointed out that the current of the generator may itself be utilised to excite the magnetism of the field magnets. It was at once seen that the induced currents generated by the influence of permanent magnets on moving coils are capable of producing far more powerful magnets than the permanent magnets. Consequently, if in the field of these magnets obtained by means of the induced currents coils are made to move, induced currents of greater strength than the first may be generated. Wilde carried out this suggestion by using a small steel permanent magnet and larger electro-magnets, in the machine represented in Fig. 219. This machine consists of two Siemens machines placed one over the other, the auxiliary machine I and principal machine II. The permanent magnets M M of machine I

generate, by means of their pole-pieces *c c*, currents in the cylindrical armature *n*, which are conducted through *a b* to the electro-magnets E E of machine II. Between the pole-pieces K K of the electro-magnets E E another cylindrical armature *m* rotates.

The powerful currents obtained with this machine were soon devoted to practical purposes. Wilde's machine, however, had one great drawback, which became the more objectionable the longer the machine was in use, viz., the mass of iron became in a short time so hot as to cause a decrease in the strength of the current. This made the generation of currents of a uniform strength impossible. Indeed, unless the armatures and coils were artificially cooled, the machine could only be worked for a short period without being permanently injured by the heat generated.

The Dynamo-Electric Principle.—The next great improvement of these machines arose from the discovery of what may be called the dynamo-

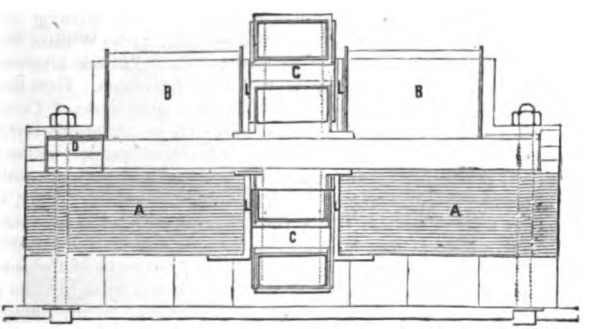


Fig. 220.—Soren Hjorth's Diagram.

electric principle. This principle may be stated as follows:—For the generation of currents by magneto-electric induction it is not necessary that the machine should be furnished with permanent magnets; the residual or temporary magnetism of soft iron quickly rotating is sufficient for the purpose.

Before this discovery, Soren Hjorth seems to have perceived that the current itself may be used to strengthen the magnets that produce it. Soren Hjorth, when describing his machine, for which he took out a patent on October 14th, 1854, says: "The permanent magnets may be wound with wire in the same way as the electro-magnets, which has the advantage of securing the permanency of their magnetism." From his description we see that Hjorth was very near the discovery of the dynamical principle; but he cannot actually claim the discovery of it, as will be seen, especially when we study the drawing which accompanied his description, shown in Fig. 220: A A represents the *permanent* magnets, B B the electro-magnets, and C C the inducing coils, which are made to rotate between the poles of the magnets. And nothing came of this patent in the way of practical application.

In 1858 an unknown inventor secured provisional protection under British patent laws in the name of J. H. Johnson, a patent agent, for a dynamo-electric machine. His specification contains the following words : "It is also proposed to employ the electro-magnets in obtaining induced electricity, which supplies wholly or partially the electricity necessary for polarising the electro-magnets, which electricity would otherwise be required to be obtained from batteries or other known sources."

In 1867 the principle was clearly enunciated and used simultaneously, but independently, by Siemens* and by Wheatstone. They both discovered that a coil rotating between the poles of an electro-magnet will, by means of the feeble residual magnetism of the core, induce a small current, and that this small current, when transmitted through the coils of the same electro-magnet, will exalt its magnetism, and so prepare it to induce still stronger currents. They

* Electrical science owes so much to the Brothers Siemens, that the following details may not be without interest to the readers of a popular treatise :—Werner and Charles William Siemens were born at Leuthe, in Hanover. They were educated at the Gymnasium at Lübeck, afterwards at the Polytechnic School at Magdeburg, and finally at the University of Göttingen. Here they studied under Wöhler and Himly. In 1842 Charles became a pupil in the engine works of Count Stolberg, and here he laid the foundation of the engineering knowledge which he afterwards turned to such good practical account. The fact that these brothers belonged to a family of inventors makes it rather difficult to say what was the precise personal share each had in the many inventions for which the world is indebted to the four gifted brothers, Werner, William, Carl, and Frederick. It may, however, be said that in electrical discovery the two brothers William and Werner were principally associated. It was to introduce to the English public a joint invention of his own and his brother Werner in electro-gilding, that William Siemens first came to England in 1843. The details of the construction of the Siemens machine, and the various improvements by which it has been brought to its present form, or rather forms (for there are, of course, several varieties), are due alike to the younger and the elder brother. And the same may be said of the various inventions connected with telegraphy and the electric light which emanated from the great firm of Siemens Brothers. Some of these were entirely worked out by one, some by the other brother, but no attempt was made to separate them or to discriminate between them. To record fitly what they and their firm have done for the advancement, not only of electric lighting, but of the various practical uses of electricity, would involve the enumeration of an infinity of technical details, each comparatively unimportant, but each fitting into its own place, and serving to produce a complete whole. It may, however, be said that if a careful examination were made of most working installations of the electric light, it would be found that a very considerable portion of the real work done had been done by the firm of Siemens Brothers. At the Paris Exhibition they were *facile principes;* at Munich, at Vienna, at the Crystal Palace, they were alike conspicuous. Visitors to the Fisheries, the Health, Inventions, and other Exhibitions, will remember how large a share of lighting there was effected by Messrs. Siemens. The electrical transmission and conveyance of power is another field they have made peculiarly their own. With the exception (and an exception of undoubted importance) of storage batteries, the advances in this direction are principally due to them. The Berlin electric railway and that at Portrush are alike the work of one or other branch of the firm, while those who ever had the pleasure of being shown round his country house, near Tunbridge Wells, by Sir William, can best realise how much he individually did to reduce to human servitude the forces of that mysterious power of which he was so great a master. Not only did electricity perform a large part of the actual work of the farm, sawing wood and pumping water, but it was made to supply in part the place of the sun itself, and assist the growth of plants and fruits. In April of 1883 Dr. Siemens received the honour of knighthood, in recognition of his scientific discoveries, and on November 18th, the same year, he died. "Looking back along the line of England's scientific worthies, there are few who have served the people better than this, her adopted son; few, if any, whose life's record will show so long a list of useful labours."

therefore placed the coils of their large fixed electro-magnets (or, as we may term them, the field magnets) in circuit with the coils of the rotating armature, so that the coils of the field magnet would be traversed by the whole or by a portion of the induced currents. Such machines are known as dynamo-electric machines, or generators, to distinguish them from the generators in which permanent steel magnets are employed, and which are termed magneto-electric generators. The reason for the name is, that in the machines which have no permanent magnet the currents seem to be more directly traceable to the dynamical power that drives the machine. It must not be forgotten, however, that in both kinds the current is due to magneto-electric induction, and the energy of the currents induced is derived from the power of the steam-engine or motor which performs the work of moving the rotating coils.

On December 24th, 1866, Mr. Varley, S.A., filed in the British Patent Office

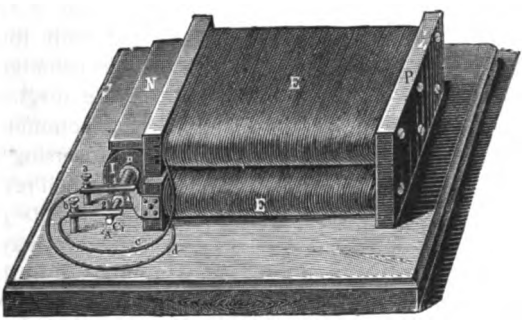


Fig. 221.—Principle of Siemens' Dynamo-Electric Machine.

a provisional specification for a dynamo-electric machine, but this was not published until July, 1867.

It was in February, 1867, that Dr. C. W. Siemens' classical paper on the conversion of dynamical into electrical energy without the aid of permanent magnetism was read before the Royal Society. Strangely enough, the discovery of the same principle was enunciated at the same meeting of the Society by Sir Charles Wheatstone, while, as we have already seen, there is yet a third claimant in Mr. Varley, who had previously applied for a patent in which the idea was embodied. It can, therefore, never be quite certain who was the first discoverer of the principle on which modern dynamo-machines are constructed. As regards the Siemens discovery, the originator of the idea seems to have been Dr. Werner Siemens, who, on being shown an electrical motor constructed without permanent magnets, immediately saw that a generator without permanent magnets was equally possible; but, as we have said, it was the second brother, Charles, who read the paper on the subject.

Fig. 221 shows the dynamic machine by Siemens in its simplest form. To

the vertical iron plate P two horizontal plates are fastened, wound with several layers of copper wire, and thus forming the limbs of an electro horse-shoe magnet, the upper pole of which is seen at N. Between the poles of this electro-magnet the cylindrical armature *n* rotates rapidly round the horizontal axis A. Fig. 222 will help us the better to understand Siemens' dynamo-electrical machine. The hollows cut in the poles of the electro-magnets E E are indicated by the dotted lines. The cylindrical armature in the figure has only one turn of wire, so as to show distinctly the mode of connection of one end with the axis A X, and the other end with the insulated metallic cylinder M. In neither of the diagrams in the figure is a commutator represented for reversing the connections every half-revolution, so that the currents generated in the armature may have the same direction in the outside circuit *c d*, consequently the arrangement represented will produce alternating currents in *c d*. When the armature rotates about the axis A X in the direction of the arrow, the pole-face *s s* approaches the upper plate N N of the electro-magnet E, and the pole-face *n n* the lower plate S. When a current from a battery is passed through the turns of the electro-magnet for a short time, a small amount of residual permanent magnetism will remain in the electro-magnet after the battery is removed. Let us assume north magnetism to be left in the upper plate N N, and south magnetism in the lower S. This magnetism will affect the iron matter of the armature, and generate in the cylindrical face *n n* north magnetism, and in the face *s s* south magnetism, according to the known

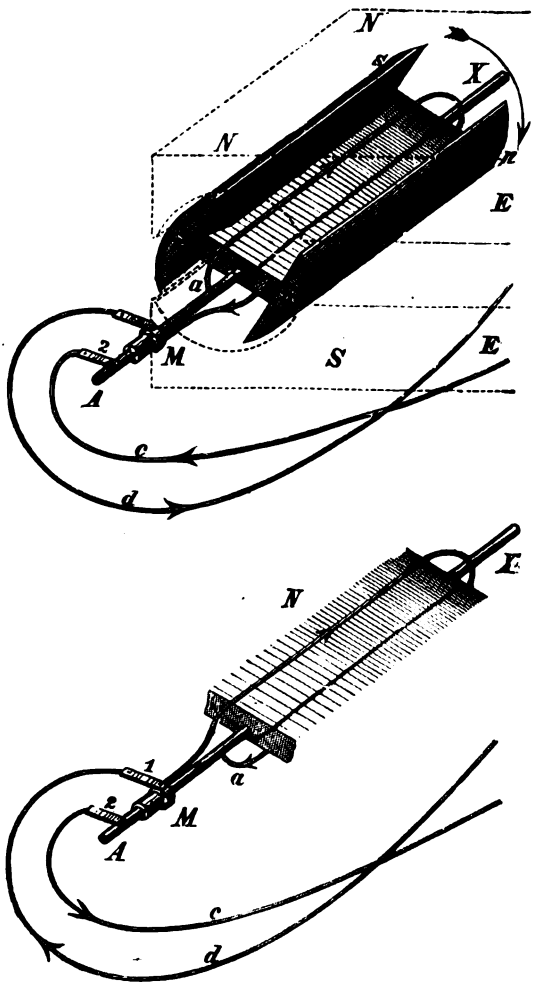


Fig. 222.—Siemens' Armature.

laws of magnetic induction. We know, further, that the production of this magnetism generates currents in surrounding conductors, the direction of which is opposite to the direction given to the magnetic current by Ampère's rule. In *s s* the Ampère currents flow with the hands of a watch, in *n n* against the hands of a watch. The residual magnetism in N N and S, therefore, induces a weak magnetism in *s s* and *n n*, which induces a current in the turns of the coil. By means of the springs 1 and 2 this current is conducted to the coils of the electro-magnet E E. The poles of the electro-magnet N and S are now not only influenced by the residual magnetism, but also by the electro-magnetism generated by the weak induced current, which therefore increases their power. This causes induced currents of greater strength to appear in the armature, and to pass into the electro-magnet, and thus again increase its power, etc. The mutual action between magnet and armature causes the progressive increase of the current's strength up to a point depending upon the construction of the machine and the velocity with which it rotates.

In the position shown in the top diagram the coil of the armature has currents which flow in the direction indicated. If the cylinder continues to rotate, the current increases for a quarter of a revolution, then decreases for a quarter of a revolution. A position is then reached where the coil is currentless. After this position the induced currents change directions, as shown in the second diagram, increase for a fourth of a revolution, and then decrease until the coils of the armature are again currentless; after this the induced currents of the first direction are reached again. The currents rise to a maximum and decrease to a minimum once during each half-revolution, as already explained in describing Clarke's machine.

In order to send the induced currents in the same direction through the turns of the electro-magnet, the machine has to be connected with a commutator, as only under these conditions is a progressive increase of the strength in the magnet possible. It is indeed still to be explained how the magnetism increases, although the machine sends no continuous currents through the turns of the electro-magnet. If the magnetism produced in the iron plates of the electro-magnet were to disappear entirely at the moment when the current ceases, the machine would be incapable of producing the effects described. We know, however, from experiment, that the magnetism of the soft iron does not cease at once, and as the cylinder rotates very quickly, a new current flows through the coil before the iron is entirely demagnetised. Although these properties of the molecules of iron are of use in the electro-magnets, they are disadvantageous in the armature, for the cylinder having to change its polarity continually, the resistance to demagnetisation causes considerable heating of the armature.

If it were not for this resistance, the electromotive force induced in the coils would increase in direct proportion to the speed at which they were driven. Hence, if the change of magnetisation could take place instantaneously, the only limit to the electromotive force which these machines could produce

would be that imposed by the mechanical resistance. Practically, owing to the coercive force of even the softest iron, and the self-induction of the wire in the bobbins, the change of magnetisation occupies a sensible time, and if the speed be increased beyond that at which the change can be completed, the electromotive force will decrease. The effect of the coercive force is diminished by making the core hollow, and the effect of useless induction is diminished by splitting the core from end to end, or by using wires instead of a solid core.

Ladd's Machine.—Instead of carrying the whole of the current of the main circuit round the electro-magnet, some inventors have shunted a portion of the main current for use, and carried the other portion only round the electro-magnet. Mr. Ladd, however, uses two distinct coils on two armatures, one of which carries sufficient current to excite the magnet, and the other conveys the current induced in it for use outside the machine. Fig. 223 represents a machine constructed by Ladd, and exhibited at the Paris Exhibition of 1867. It consists of two electro-magnets and two Siemens cylindrical armatures. The two electro-magnets B and D consist of iron plates, which have at their ends A A, free from wire, semicylindrical hollowed-out pole-pieces, the pole-pieces of the magnet B having the letters C C and C′ C′ in the figure. The two cylindrical armatures have commutators at *m* and *n*, the springs F and F′ each leading to two screws. The rotation of the cylinders is brought about by transmission belts. The springs F, which slide on the smaller cylindrical armature, are so connected with the wires of the electro-magnets B D, that the wires of the magnets and armatures form a closed circuit. The wires in the electro-magnet are so arranged that at every cylindrical armature two opposite poles stand opposite to each other. The right-hand half of Ladd's machine is simply a Siemens dynamo-electric machine. Whenever the machine is put in motion the residual magnetism induces weak currents in the two armatures. The currents generated in the smaller armature *n* are conducted into the coil of the electro-magnet, and increase the strength of the magnet; then, owing to the mutual action between magnet and armature, the strength of the currents increases progressively, until the resistance to the motion of the armatures as they pass the poles balances the driving power. The currents generated in the right-hand armature are only used for the electro-magnets, whilst the currents

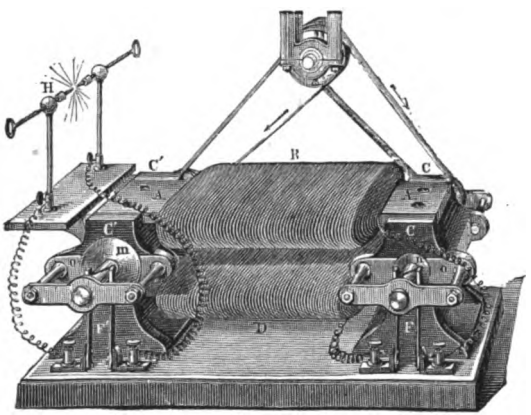


Fig. 223.—Ladd's Machine.

generated in the left-hand armature may be utilised in the outer circuit, as for instance an electric light at H.

The Ring Armature.—The starting-point of a great improvement in dynamo-electric machines, was the discovery by Pacinotti of the ring armature. This armature is a toothed ring of iron, with wire wound between the projections. Dr. Antonio Pacinotti constructed his first electro-magnetic machine in 1860. The drawing shown in Fig. 224 is taken from "La Lumière Électrique," and represents the model machine exhibited at Paris in 1881. The machine was first constructed as a motor, that is to say, it received electricity from without and transformed it into work.

The following is a translation of the original paper in Italian, in which Dr. Pacinotti describes his machine:—

Description of a Small Electro-magnetic Machine by Dr. Antonio Pacinotti.

In 1860 I had occasion to construct, for the Museum of Technological Physics of the University of Pisa, a small model of an electro-magnetic machine devised by me, an account of which I now decide to publish, especially in order to make known an electro-magnet of a particular kind employed in the construction of the said machine, which seems to me to be adapted to give greater regularity and steadiness of action in such electro-magnetic machines; and is of a form suitable for collecting the sum of the currents induced in a magneto-electric machine.

In ordinary electro-magnets, even when a commutator is adapted thereto, the magnetism always appears in the same positions; whilst with the commutator which is united to the electro-magnet that I describe, the poles can be made to move in the iron. The form of the iron of such electro-magnet is that of a circular ring. In order to easily understand the movement and the mode of action of the magnetising current, let us suppose there be wound upon our ring of iron a copper wire covered with silk, and when the first spiral is finished, instead of continuing the helix by going over that already constructed, let the wire be closed by soldering together the two ends that come near each other. In this manner we shall have covered the iron ring with a closed insulated spiral directed entirely in one way. Now if we connect the poles of an electric battery with opposite points of the wire of this helix on one side and on the other of the ring, the direction the current takes will be such that the iron will become magnetised, presenting the magnetic poles at the places where the conducting wires are applied. The direct line that unites these poles may be called the magnetic axis. By changing the points in communication with the battery we may give any position to this magnetic axis transversal to the figure or ring of iron of the electro-magnet. I, therefore, like to consider such a ring as two transversal semi-circular electro-magnets placed in juxtaposition, and having the poles of the same name in contiguity. In order to construct on such a principle the electro-magnet with which I mounted the small electro-magnetic machine, I took a turned iron ring, having the shape of a toothed wheel, with sixteen equal indentations. This ring was supported by four brass radii, B B′, which unite it to the axis of the machine. On each tooth of the ring I placed a small triangular prism made of wood, and so I left hollow grooves, within which I could wind copper wire covered with silk. I have succeeded in placing between the teeth of this iron wheel a number of helices or electro-dynamic coils well insulated. In

all these the wire is wound in the same direction, and each of them has nine spirals. Any two consecutive bobbins are separated from each other by an iron tooth of the wheel, and by the little piece or triangular prism of wood. Passing from one bobbin to construct the following one, I have left free a tassel or fork of copper wire, fixing it to the piece of wood which separates the two bobbins. On the axis on which the wheel so constructed rotates I have brought all the tassels that

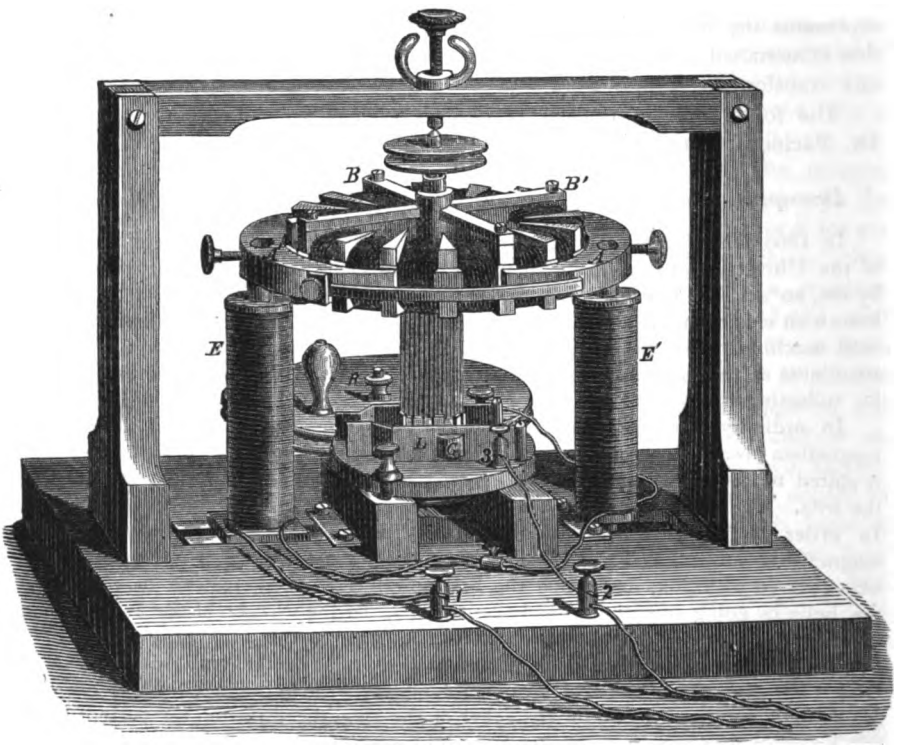


Fig. 224.—Pacinotti's Machine.

with one end form the termination of one bobbin, and with the other the beginning of the next one, making them pass through convenient holes in a wooden collar centred on the same axis.

This commutator consists of a small cylinder of wood, with two rows of grooves around the cylindrical surface, in which sixteen copper pieces are inlaid, eight on the upper portion and as many below ; the first alternating with the second, all being concentric with the wooden cylinder, and a little projecting and alternating with the wood. Each of these small pieces of copper is soldered to the corresponding tassel joined between the two bobbins, so that all the bobbins communicate with

each other, each deing uniteb to the next by a conductor, of which one of the small pieces of copper of the commutator itself makes part. Putting two of these in communication with the poles of a pile by means of two small metallic wheels, the current will divide and will run through the helix on one side and the other of the points, whence the tassels start, united to the two small communicating pieces, and the magnetic poles shall appear in the iron of the wheel. Upon such poles act the poles of a fixed electro-magnet E E', and determine the rotation of the transversal electro-magnet around its axis. Even when the electro-magnet is in motion, the poles are always produced in the same position, which correspond to the communications with the pile.

This fixed electro-magnet, as appears by Fig. 224, is composed of two iron cylinders E E', joined together by an iron cross-piece, to which one is permanently screwed, and the other is fastened by a screw, placed underneath, which allows it to run along a groove, in order to make the poles of the cylinders E E' approach or recede from the teeth of the wheel. The current of the pile entering from the conducting wire 2 passes through a wire to the communication 3, and from that to the little wheel G, circulates around all the bobbins of the wheel, and returns through the connection 4, which makes it pass through another copper wire to the helix, which surrounds the cylinder E'. From this, coming out again, it passes to the helix of the cylinder E, and is conveyed through another copper wire to the second conducting wire 1. I have found it very advantageous to add to the two poles of the fixed electro-magnet two soft iron armatures A, A', each of which embraces for more than one-third of the circle the wheel that constitutes the transversal electro-magnet, placing them very near to the teeth of the same, and tying them together with copper guides.

The machine works when the current passes only through the circular electro-magnet, but it has much less strength than when the current passes also through the fixed electro-magnet.

The reasons that induced me to construct the small electro-magnetic machine upon the system described were the following :

(1) In the method adopted the current never ceases to circulate in the helices, and the machine does not move by a series of impulsions that succeed each other more or less rapidly, but by a union of forces that act continuously.

(2) The circular construction of the revolving magnet contributes, together with the preceding method of successive magnetisations, to give regularity to the movement and the least expenditure of actual force in shock or friction.

(3) In it nothing is sought but that the magnetisation and demagnetisation of the iron of the electro-magnet be accomplished instantaneously, to which are opposed both the extra currents and the coercive force, of which the iron can never completely get rid ; but it is only required that every portion of the iron of the transversal electro-magnet, subjected always to the convenient electro-dynamic forces, pass successively through the various degrees of magnetisation.

(4) The external armatures of the fixed electro-magnet continuing to act upon the teeth of the electric wheel, and embracing very many of them, do not abandon its (the wheel's) action while magnetism remains in them. The sparks are increased in number, but much decreased in intensity, inasmuch as there are no strong outside currents on the opening of the circuit, which may always be kept closed, and it is only when the machine acts that an inducted current continues directed in a contrary course from the current of the pile.

Pacinotti not only constructed this machine as a motor, but also as a generator of electricity. He says: "If permanent magnets are taken instead of the electro-magnet E E', and the transverse magnet (the ring) is caused to rotate, we shall have a magneto-electro machine which will produce a continuous current of the same direction."

A machine exhibited at Paris in 1867 by Kravogl in certain points resembled Pacinotti's machine. Kravogl did not intend his machine as a generator of electricity, but as a motor worked by electricity.

Professor Pfaundler (1870) obtained a continuous current of the strength of one Bunsen element by making a Kravogl motor rotate. Neither Pacinotti or Kravogl, however, could bring their machines to such perfection as to ensure their being adopted for practical use.

The Ring and Drum Armatures.—Gramme, in 1871, modified the ring armature, and constructed the first machine, in which he made use of the Gramme ring and the dynamic principle. In 1872, Hefner-Alteneck, of the firm of Siemens and Halske, constructed a machine in which the Gramme ring is replaced by a *drum armature*, that is to say, by a cylinder round which wire is wound (as will be subsequently described in detail, see p. 268). Either the Pacinotti-Gramme *ring* armature, or the Hefner-Alteneck *drum* armature, is now adopted by nearly all constructors of dynamo-electric machines, the parts varying of course in minor details.

The resistance of the wire in the various armatures is varied, as the machine is used for different purposes. It is found that the best length and thickness of wire depends on the resistance through which the current is required to flow in the outside circuit. If this resistance is small, the coils of the magnet should be made of thick wire; if the external resistance is great, then the coil should be composed of many turns of thin wire. Sir William Thomson finds that for a series dynamo the resistance of the field magnets should be a little less than that of the armature, both being small compared with the resistance of the external circuit.

For a shunt dynamo the external resistance should be a mean proportional between the resistance of shunt coils and armatures. But these points will be discussed at length after we have described in detail the principal kinds of generators and motors.

Classification of Dynamo-Electric Machines.—Very little reflection on the principles we have already established will show the advantages of the following points in the construction of dynamos. These have to be considered in different degrees, as all cannot be secured at the same time.

1. The field magnets should be as strong as possible, the poles being near together.

2. The armature coils should be of thick wire, that they may not introduce unnecessary resistance.

3. At the same time the length of wire used in the armature coils should be as great as possible consistent with the preceding rule.

4. The currents, both for lighting and for work, must be steady, and therefore the magnet poles must be so shaped and arranged as to distribute the field evenly. Opposing inductions will be produced in some of the coils, but these should be as far as possible minimised by the distribution of the field, and by cutting out of the circuit certain coils during the short interval in which they carry currents opposing the general or main current.

5. Useless internal currents must be avoided, as, if they do no other harm, the heat the machine. Hence the cores are usually split, and consist of wires or thin plates, according to the shape of the armatures.

6. Useless resistance and "idle" wire are to be avoided in all parts.

7. Sparking at the brushes or elsewhere produces a destructive waste, etc.

The various inventions to secure the greatest number or the most important of these aims, furnish us with the means of classifying modern electric machines.

Thus we have :

1. Magneto-electric machines, in which there are permanent magnets.

2. Dynamo-electric machines, which rely on the residual magnetism of the cores to start the current.

The latter may be divided into the following classes :

a. The *series dynamos*, in which the coils of armature and electro-magnet are joined up in series.

b. The *shunt dynamos*, in which a portion of the current is shunted for use.

c. The *separately-excited dynamos*, in which the electro-magnets are fed by an auxiliary machine.

d. Combinations of *a*, *b*, and *c*.

Again, dynamo machines may be :

1. *Generators* when they produce electricity at the cost of work

2. *Motors* when they receive electricity and do work. A machine which may be used either as a generator or motor is said to be reversible.

The various modern dynamo-electric machines differ either in :

(A) The arrangement of coils in the rotating armature.

(B) The arrangement of coils on the fixed or field magnets.

(C) The commutator.

A. i. *Cylindrical armatures* have the wire wound lengthwise on a grooved cylinder.

ii. *Ring armatures* have the coils wound round a ring. There are two kinds, the anchor ring and flat ring.

iii. *Drum armatures* have the coils on a plate or drum.

iv. *Disc armatures* have the coils on a plate or disc.

B. i. *Continuous coils* send the same current round the coils of the field magnet and the coils of the armature.

ii. *Shunted coils* allow a part only of the main current to pass through the coils of the field magnets.

iii. *Separately excited coils* are used when the current of the magnets is produced by a separate arrangement.

C. *Continuous current commutators* are of the forms:

i. *The two part commutator*, or overlapping cylinders.

ii. *The split tube.*—The various moving coils are connected with what is called a split tube, consisting of bars on a cylinder of insulating material, and these bars touch the brushes or springs alternately, so that for one part of the revolution the bar of any coil touches one brush, and for the opposite part it touches the other brush. A continuous current therefore traverses the exterior wire. The brushes may be simply springs or pieces of copper wire, soldered at one end into a layer or bundle.

iii. *Alternating currents.*—These are required for lamps where the carbons have to be consumed at equal rates, such as the Jablochkoff candle. The field magnets for an alternate current machine must be excited by a supplemental generator.

MAGNETO-ELECTRIC AND DYNAMO-ELECTRIC MACHINES.

We have now to trace the ways in which these differences are combined, and the modifications that are introduced into the principal machines bearing the names of patentees or inventors.

MAGNETO-ELECTRIC MACHINES.

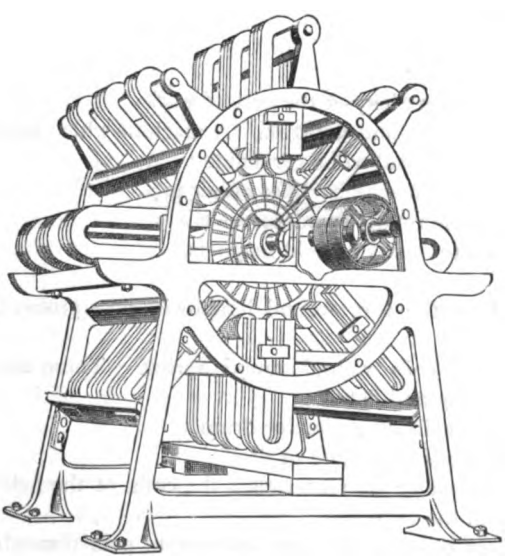


Fig. 225.—The Alliance Machine.

The Alliance Machine is represented in Fig. 225. It consists of eight sets of compound horse-shoe magnets fixed symmetrically, as shown; each compound magnet weighs about 45 lbs. The machine, it will be readily seen, is, in principle, an assemblage of Clarke machines, and has twice as many coils as magnets, thus, with forty-eight magnets there are ninety-six coils. One end of the total length of wire is fastened to the axis, and is, therefore, in electrical connection with the frame of the machine; the other end is fastened to a metal ring surrounding the

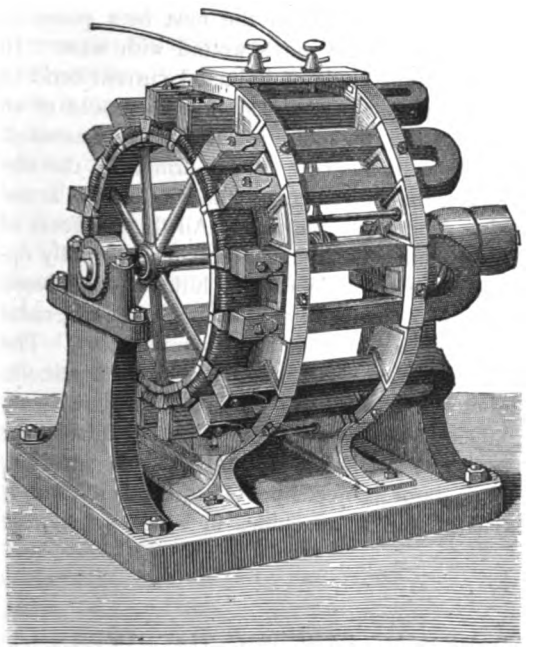


Fig. 226.—De Meritens' Machine.

shaft but insulated from it. A spring which presses on this ring conducts away the current. Every time a spool passes a pole the current changes, hence there are sixteen changes for each spool to each revolution, and as the machine is driven at more than six revolutions per second, there will be 100 changes per second. The first machine of this kind had commutators; but it was only after the machine was modified by Van Malderen, who abandoned the commutator so as to use the rapidly alternating currents, that it became of practical value. Alliance machines were used in the electric lighting on Mont Valerien and Montmartre during the siege of Paris in 1871, and have been used in some light-houses on the coast of France ever since that date. Nevertheless, this form of machine is complicated and costly, and not easily repaired when any part is injured.

De Meritens' Machine.—In the construction of De Meritens' machine permanent magnets are also used, as represented in Fig. 226, arranged so that the poles alternate at equal distances round a circle. The armature rotating within this circle consists of a wheel, on the rim of which are fixed fifteen cores with their coils. The cores are each composed of many laminæ of sheet-iron of ⊏ shape, round which a covered wire is wound in the manner clearly shown in Fig. 227, which represents one of the magnets and three of the cores and coils, one of them

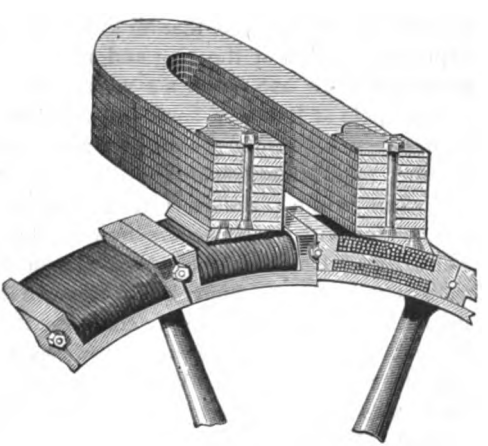


Fig. 227.—De Meritens' Armature.

shown in section. Each iron core is separated from the next by a piece of copper, and the whole forms a complete ring of cores wound with wire. In this arrangement it will be seen that several kinds of inducted current tend to strengthen each other, or at least act in the same direction. As a pole of an armature core approaches any pole of the magnets, a current is generated. The magnet-pole further generates a pole in the core of the armature, thereby also generating a current; and thirdly, the movement of the wire of the armature through the magnetic field also generates a current. All these effects of induction coincide in direction. On the other hand, as currents diametrically opposite are generated as the armature *leaves* the pole we have hitherto considered it as approaching, the current delivered to the external circuit is of an alternate character, which might however be made continuous by a commutator. The coils also, though all wound the same way, must be joined up in a particular manner, which avoids the contradictory currents that would otherwise be produced. This machine is of high efficiency, and has a reputation for light-house illumination: its armature coils are very easily wound and fixed in position, and for alternate currents no commutator is needed. On the other hand, it possesses all such disadvantages as pertain to machines in which permanent magnets are employed.

CONTINUOUS-CURRENT DYNAMO-ELECTRIC MACHINES.

The Gramme Machine.—We have now to describe in detail the principal types of dynamo-electric machines. The first requiring description is the *Gramme* machine. The principal feature is the ring armature, invented by Gramme. It consists of a bundle of annealed iron wires bent into a circle, and completely overwound with copper wire in sections, each section being connected with the next, so that all the coils are connected in series. In order to explain the action of the ring and its coils, or bobbins, let us refer to the diagram in Figure 228. A N B S represent a ring-shaped magnet, having a north-seeking pole at N, and a south-seeking pole at S. Eight coils are shown in the figure, each being represented by a single turn of wire. Let us imagine the coils to move round the ring in the direction of the arrow, and trace the effects of induction in the positions 1 to 8. We may adopt any of the three modes of explanation with which we are now familiar, Ampère's rule, Lenz's law, or Maxwell's rule. Consider the application of Lenz's law. The current induced is such as to resist the motion; hence, as a coil leaves a south pole, the south pole pulls it back. Hence the retreating coil presents the dissimilar pole to that which it is leaving. As a coil passes from S towards A, therefore it has its *n* side towards S, and its *s* side forward. When, however, it has passed A, the pole N repels it by Lenz's law, and therefore the *n* side of the coil is forward and the *s* side behind. Hence a change of direction of the current takes place at A. Faraday's principle and Maxwell's rule give us more information about this and similar

machines than the direction of current simply, and it will be convenient here to consider Faraday's principle, which has thus been stated: When a conductor is moved in a field of magnetic force in any way so as to cut the lines of force, there is an E. M. F. produced in the conductor in a direction at right angles, both to the direction of motion and the lines of force.

The E. M. F. is proportional to the intensity of the field. By imagining the number of lines of force crossing any small area to be proportional to the intensity at every point, and passing always in the direction in which a north magnetic pole would be moved, we may say that the E. M. F. is proportional to the number of lines of force cut per second, and the direction of the current is to the right of the lines of force.

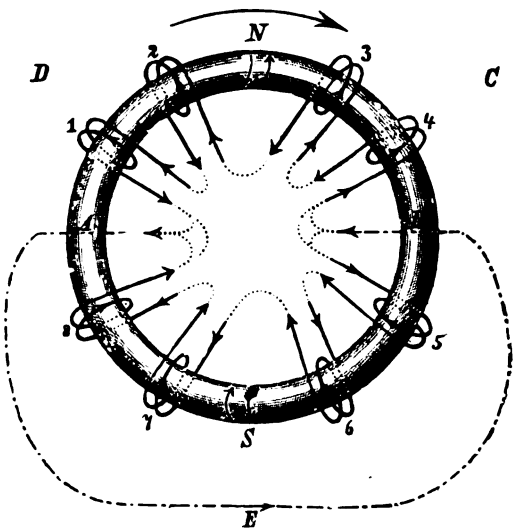


Fig. 228.—Theory of the Gramme Ring.

Suppose a figure swimming in the conductor to turn so as to look along the lines of force in the direction in which a north pole would be moved; if the swimmer and conductor be moved towards his right, he will be swimming with the induced current.

To induce currents in a conducting circuit, either the conductor must move or the magnet must move relatively to the conductor, so as to *alter* the number of lines of force embraced in the circuit.

Increase of the number of lines of force embraced produces a current in one direction, and decrease produces a current in the opposite direction.

Hence, approach and recession between a coil and magnetic pole produces alternating currents. The effects are the same with the same intensity of field, whatever may be the kind of magnet that produces the field.

To explain the series of changes by Maxwell's rule, we must imagine the lines of force drawn in the magnetic field between N and S, and consider where the number of such lines that pass through a moving coil becomes a maximum, and where it becomes a minimum.

The greatest number of these imaginary lines of force will pass through the circle of wire forming a moving coil, when it is at right angles to the line joining the poles N S, and no lines of force will pass through the coil when it lies along the line N S, so that it is presented to a pole edgewise. As a coil rises from A to N, the number of lines of force that pass through it will be continuously diminishing,

until the number becomes o at N. As it descends from N, the number of lines of force intercepted by it increases, but they pass through its plane in the opposite direction. For instance, draw two of the lines from N, one on each side, placing arrow-heads pointing from N. The arrow-heads point to the front of the approaching coil and the back of the receding coil. If the former lines be considered positive, the latter are negative. From A to N, therefore, the number of positive lines is diminishing, and from N to B the number of negative lines is increasing. Similarly from B to S the number of negative lines is diminishing, and from S to A the number of positive lines is increasing. Hence, in all the coils of the upper half the currents are in one direction, and in all the coils of the lower half they are in the opposite direction. There will therefore be a higher potential at A than at B, and consequently, if A and B be joined by an external wire A E B, there will be a current as shown by the arrow.

From the figure we can easily see that the coil, on the road from A over N to B (that is, in the positions 1, 2, 3, and 4) is chiefly influenced by the north pole; on its way from B over S to A (that is, in the positions 5, 6, 7, and 8) it is chiefly exposed to the influence of the south pole. The coil is equidistant from the N and S, when at either of the positions A B; here the induced currents will be of equal strength, but opposite in direction. It follows that for every revolution of the coil the induced currents will change their direction twice, viz., at A and B. The above not only holds good for one coil, moved in the manner described, but for every coil. Let us assume, then, the positions 1, 2, 3, 4, etc., in the figure, to represent not the different positions which one coil would have during motion, but so many coils moving in the same direction, and at the same rate, we shall have the currents of one direction in 1, 2, 3, 4, and currents of the opposite direction in 5, 6, 7, 8. If now the beginning of one spiral is connected to the end of the next, as shown in the figure by the dotted lines, all the coils will form then one continuous spiral. If the parts N and S have equal intensities, and there are the same number of coils in the upper and lower half of the ring, currents of the same strength, but opposite direction, will be produced at A and B. The resultant of all the induced currents will be zero. If now we make an addition, and not only join the spirals between A and B to one another in succession, as shown by the dotted lines, but connect the junctions on opposite sides by an external wire: then through this wire a current will flow in one direction. We shall understand how it is that the flow takes place by taking an analogous case: that of water. Imagine the two spirals 1 to 8 filled with water, as shown in Fig. 229. Suppose that at the end of each coil a piston is introduced to produce a pressure. If the pressures at C and D are equal, the water inside the coils will have no motion. When now at the junction A a third channel A B is placed, the water will flow in the direction through A B, indicated by the arrow. Suppose the same arrangement was made at B on the other side (Fig. 228), the water then would flow in the opposite direction to A B, and cause the same conditions as exist at C D.

To obtain the direction of the induced currents in spirals 1 and 2, ac-

cording to Ampère's rule, the observer must be placed at C, and they will be found to flow against the hands of a watch (indicated in the figure by the arrow under N, without a tail); for spirals 3 and 4 the observer stands at D, the currents in the spirals still flow against the hands of a watch (indicated by the second arrow in the figure, having a tail). If we follow in a similar way the direction of the Ampère currents at the south pole 5, 6, 7, and 8, we find they flow with the hands of a watch, as indicated by the arrows in the figure. A coil moving round the ring will be currentless at A. As it approaches N the induced currents will increase to a maximum at N. After the coil has passed N, again the intensity of the current diminishes. When the coil reaches B it will again be currentless. When the coils move towards S the current increases, then again decreases as the coil moves away from S till A is reached, when the coil is again without a current.

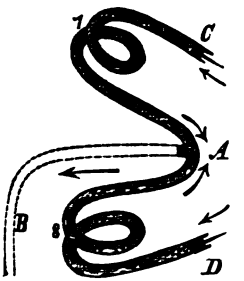


Fig. 229.—Current from two opposing currents.

We took for granted that the ring has north magnetism at N and south magnetism at S, without explaining how this is brought about. In the Gramme machine the ring is arranged between the poles of a powerful permanent magnet or an electro-magnet; and in this manner each portion of the ring nearest the north pole of the magnet becomes south magnetic, and the portion of the ring near the south pole north magnetic. As the coils of the ring rotate very close to the poles of the magnet, this will induce currents in the coils, the direction of which is easily determined by means of Ampère's rule. Following, for instance, the current which flows through coil 3 (Fig. 230), we find that the inducing effects of magnet and ring assist each other.

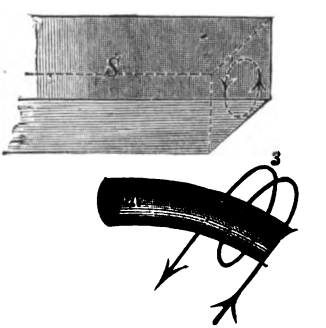


Fig. 230.—Theory of the Gramme Ring.

Up to the present we have assumed that the iron rings were fixed between the poles of the magnet, and that the coils only moved. To carry out such an arrangement practically, however, would meet with many difficulties, and the same result may be obtained by keeping the poles fixed in position while the iron moves. Experiments have shown that a soft iron ring rotating between the poles of a magnet becomes magnetised in the same manner as a fixed ring would; that is to say, so that the portion opposite the north-seeking pole of the magnet acquires south magnetism, and so on. The rotating ring, then, in relation to the poles of the fixed magnet, behaves exactly as a fixed ring would, with one slight modification: the ring does not become magnetised so as to have its poles exactly opposite to the poles of the magnet exactly at the

moment of passing the pole, but a little later. *Time* is required to secure the maximum magnetisation. In the same manner it does not lose its magnetism immediately it moves away. The poles of the ring will not lie, therefore, immediately opposite the poles of the fixed magnet, but a little farther on, in the direction in which the ring moves. They will have what is technically called a certain "lead." By taking into account these facts, we may wind the wire round the ring and make the latter rotate, without rendering the explanations given above inapplicable to Gramme's ring.

Fig. 231 represents the actual form of the complete ring armature. The ring itself does not consist of a solid piece of iron, for reasons already given, but of a bundle of iron wires well annealed. Such a ring will lose and recover its magnetism sooner, and the effect of useless induction will be less than if it con-

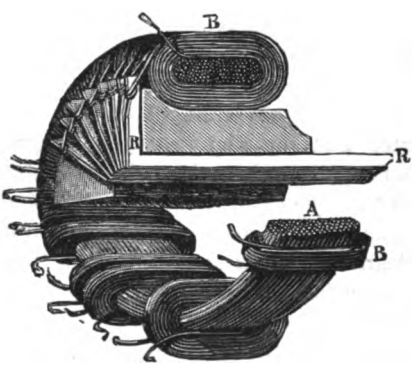


Fig. 231.—Section of a Gramme Ring.

sisted of one solid piece. A B represents an incomplete ring armature coil, the upper portion of the figure showing the completed coil. The coils consist of copper wire, well covered; the number of turns and the thickness of the wire depend, according to the principle already explained, upon the purposes for which the machine is to be used.

The connection of the coils is shown in the figure; the end of one coil and the commencement of the one next to it are soldered to copper strips R, which are bent at right angles and protrude on the other side of the ring. The number of copper strips is equal to the number of coils; these copper strips together form a hollow cylinder, and are separated by insulating substances from each other. In the middle of this hollow cylinder the steel shaft is fastened, being, of course, well insulated. The space between the copper strips and the coils is taken up by a wooden ring. To conduct away the currents induced in the Gramme ring, two wire brushes are fastened in such a manner that they slide over the end surfaces of the cylinder formed of the copper strips R R.

In the machine shown in Fig. 232 the ring rotates between the poles of a permanent steel magnet, and is used as a model for laboratory purposes and illus-

tration. Machines intended for practical use are supplied with electro-magnets, in place of the permanent magnet. Such machines are shown in Figs. 233, 234.

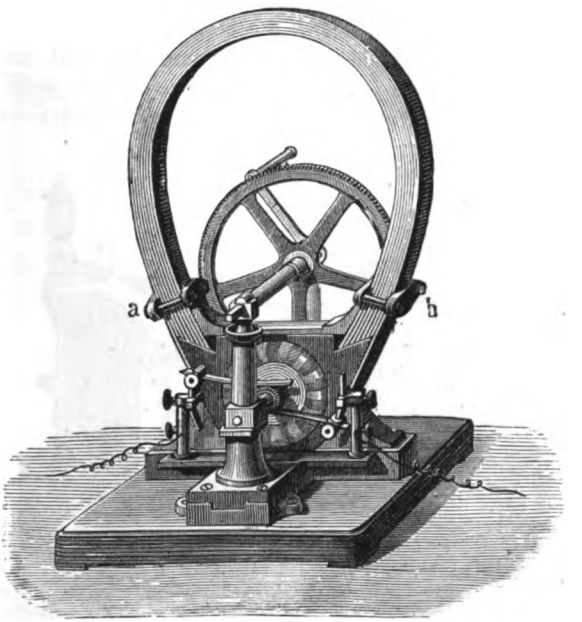


Fig. 232.—Gramme Hand Machine.

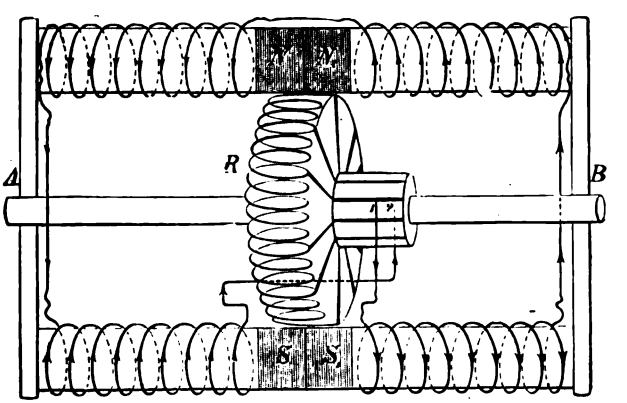


Fig. 233.—Diagram to Illustrate the Theory of the Gramme Machine.

Figure 233 is a diagram to illustrate the principle. R is the ring, which consists of a bundle of iron wires wrapped in ten sections, the ends of each of the ten coils being joined to ten strips of copper, insulated from one

another, and fixed round the axis, A B, forming a split tube collector. Each strip of copper is connected with adjacent coils, so that by means of the strips there is a continuous connection all round the coils. On opposite sides of the shaft two springs or brushes 1 2 press against the copper strips.

Suppose the external circuit leading to the lamps removed, and the terminals joined, so that the machine is *short-circuited*, the arrows showing the direction of the current. The current produced in the coil R travels to the brush 1,

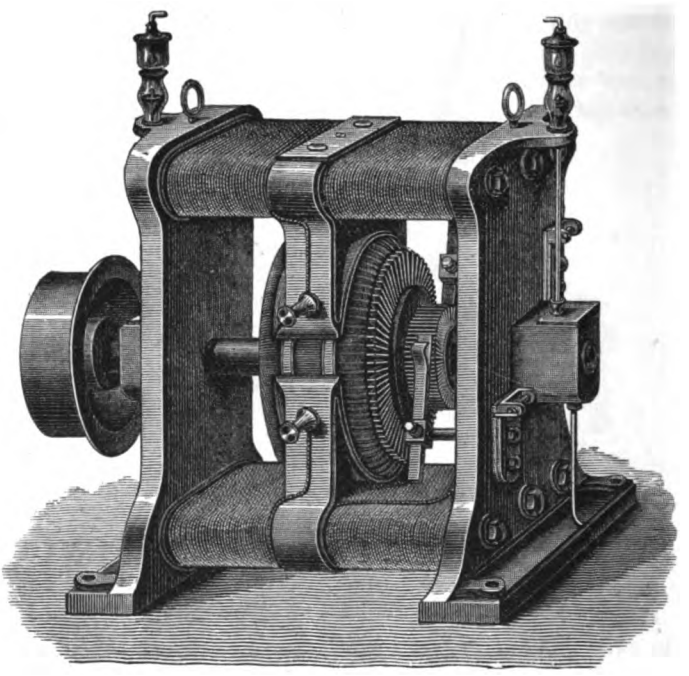


Fig. 234.—Gramme Generator for Lighting.

from 1 into the electro-magnet S_1 B N_1, thence to electro-magnet N A S, thence to the brush or spring 2, and back to the coil. In the coils moving round the upper half of the ring the currents go forward or are direct, and in the coils in the lower half of the ring the currents are inverse; but the reversion of the contacts every half revolution causes the current in the external circuit and the electro-magnets to be continuous.

Fig. 234 represents the new model; its length is 0·623 metre, height 0·538 metre, and weight 360 kilos. More recently, a machine has been constructed by Gramme, of such shape and size as to take up as little room and to weigh as little as possible. This is shown in Fig. 235, *a* and *b*. To the axis A X the ring R is fastened. The iron cores of the electro-magnets E E consist of

cylindrically bent iron plates which have coils D D wound round them. The portion of the iron cores opposite the ring are cut away at *n s* so as to allow the ring to rotate.

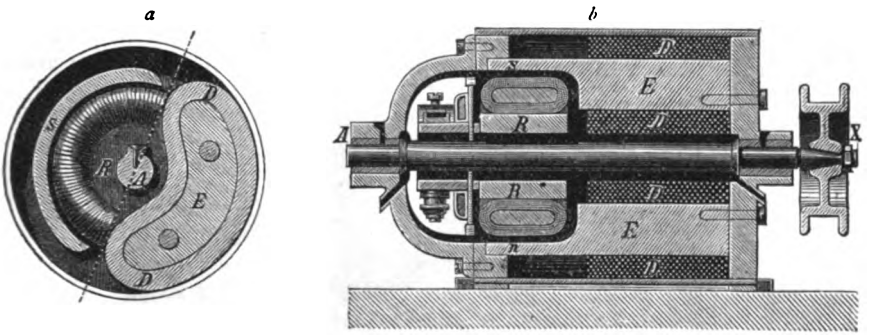


Fig. 235.—Section of Gramme Machine.

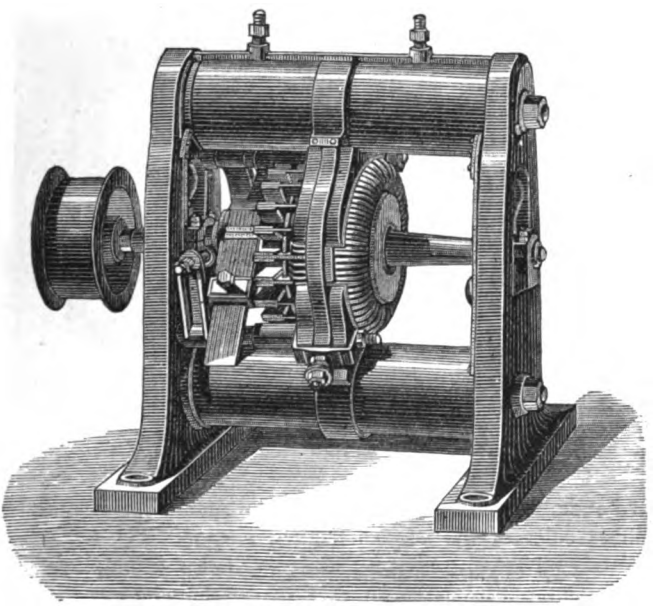


Fig. 236.—The Gramme Machine for Electrotyping

For electrotyping purposes Gramme constructed a machine which had a double ring armature, on the principle already described in connection with Ladd's machine. The currents induced in one of the armatures were employed for the electro-magnets, the currents of the other armature for doing work. With this machine, 600 grammes of silver were separated from a solution

during one hour. To work it, one horse-power was required (one horse-power =75 kilogrammetre). This machine was superseded by the one shown in Fig. 236. It is one of the latest models, and presents the following modifications: The coils of the magnets do not consist of copper wires, but of sheet metal. The uppermost layer is bright, so as to facilitate radiation of heat, and to hinder the heating of the machine. Similarly, in the coil of the ring arma-

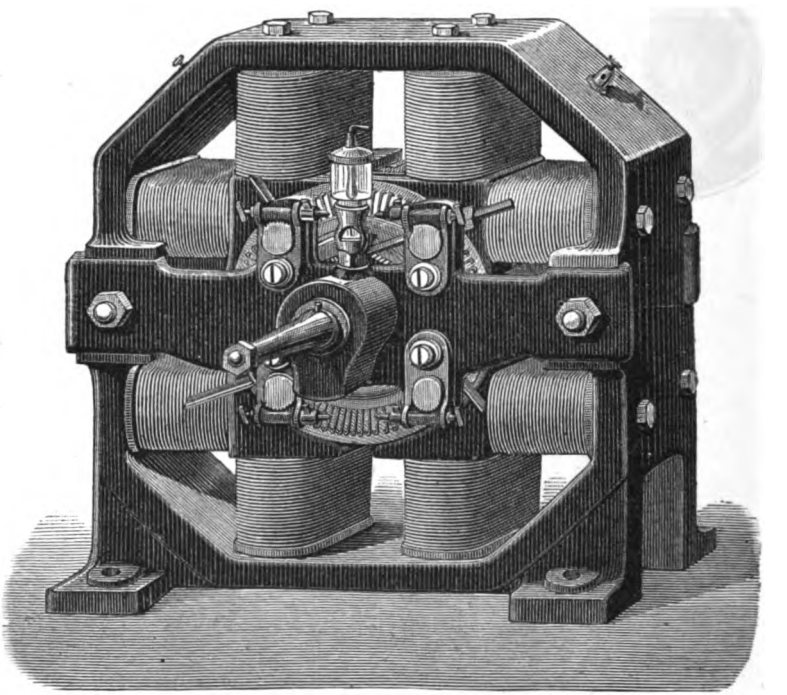


Fig. 237.—Larger Gramme Machine.

ture copper bands are used instead of copper wires. These bands are stronger than the sheet coils of the electro-magnet, because they have to resist considerable centrifugal force. No insulating substance is employed between the different groups; but care is taken that spaces shall be left between them, so that air may enter, and serve as an insulator. The reason of the above arrangement of armature and electro-magnet coils for electrolysis and electroplating is, that the quantity of electricity produced is of more importance than its potential, therefore the resistances in the machine ought to be as small as possible. The new machine weighs about one-fourth of, and does the same amount of work with two-thirds of the horse-power required for the first machine. Fig. 237 represents a machine for the transmission of power, in which

the electro-magnets are arranged in form of a double cross, and (with their pole-pieces) almost surround the ring. The working of these and similar machines we shall consider later on.

The Schuckert Flat Ring Machine.—Although at present Gramme's construction is considered for most purposes the best, it is not free from imperfections. The chief of these are the want of durability and the weakness of construction of the ring, through having a wooden core, the non-utilisation of much of the wire, and the heating of the machine itself when in motion. Schuckert endeavours to obtain a better utilisation of the various coils of the ring by making it flat, so that its cross section represents an oblong. Schuckert's flat ring machine is shown in Fig. 238. The wooden core of the Gramme ring is replaced by an iron core, whereby the loosening of the different parts of the ring is almost entirely prevented. The iron core consists of short metal pieces insulated from each other so as to facilitate magnetisation and demagnetisation; above the core the different coils are arranged, the ends being connected, as in the Gramme ring. The commutator is of the split tube kind, and has to be divided into as many portions as there are coils in the ring. The connection of the wire ends with the portions of the commutator is not brought about by soldering them, but by screwing them together. This plan has the advantage of rendering a reserve armature unnecessary, and making it easy to replace any one of the coils. The ring is also placed in the vertical stand in such a way as to facilitate its removal. Broad bearings and well-arranged lubricators for the shaft do much to secure the quiet and steady working of the machine. The induction current is produced by two electro-magnets, the arms of which are horizontal, and are connected by means of the iron supports of the machine. Pairs of poles standing opposite each other produce a north magnetic and a south magnetic field, through which the ring rotates. Schuckert allows as much space as possible between the poles of the upper arm and the poles of the lower arm of the electro-magnet, so as to give the iron core in the ring time to become completely magnetised, once with north magnetism, and once with south magnetism, in each revolution.

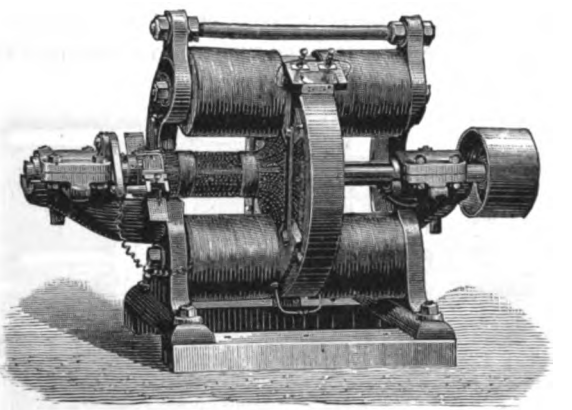


Fig. 238.—Schuckert Flat Ring Machine.

Fig. 239 represents a machine constructed by Schuckert for galvanoplastic or electrotyping purposes. In this machine we observe a commutator at each

end. To understand the reason for this arrangement, we must consider the nature of the work the machine is intended to do. We remember that during electrolysis the plates as a rule become polarised, and then produce an opposition current. We also know that dynamo-electric machines are started by means of the weak residual magnetism of the electro-magnets' iron cores; also, that the electro-magnets are demagnetised when the machine stops, or weakened when it rotates more slowly. When the machine stops, and remains in connection with the products of decomposition, the polarisation current (opposite to the machine current) will flow into the coils of the machine, and

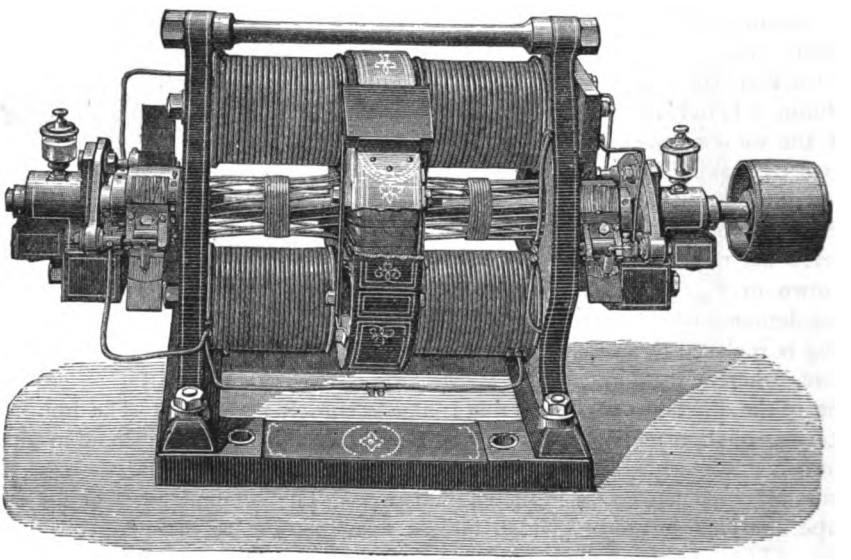


Fig. 239.—Schuckert's Machine for Electrotyping.

give the iron poles a residual magnetism which is opposite to the magnetism the iron had previously. If the machine does not stop entirely, but only slackens its speed, it depends upon the strength of the polarisation of the electrodes whether the polarisation current or the machine current determines the magnetic polarity in the machine. We see then that the magnet poles in the machine are liable to be changed, and, in consequence, a change is liable to occur in the direction of the current also. The consequence of this would be that the work done by the first current (for instance, decomposition of silver) would be destroyed by the second (which would bring the silver again into solution). This changing of poles, then, is what Schuckert wishes to prevent by using two commutators. The coils or bobbins of the flat ring are divided into two groups; one group is connected with the left-handed commutator, the other group with the right-handed commutator. Currents from

one of the commutators are used for magnetisation of the electro-magnets, the currents of the other are conducted into the electrolytic cells. The construction of the machine is the same as that of the machine for lighting purposes; but the number of turns of wire in the armature and electro-magnets are considerably reduced, and the diameter of wires so enlarged as to produce *quantity*, instead of high potential or tension.

The Gülcher Machine.—The flat ring machine by Gülcher has been constructed to suit his lamps, and is required to produce currents of small tension, or low potential, but great quantity. In order to obtain this result,

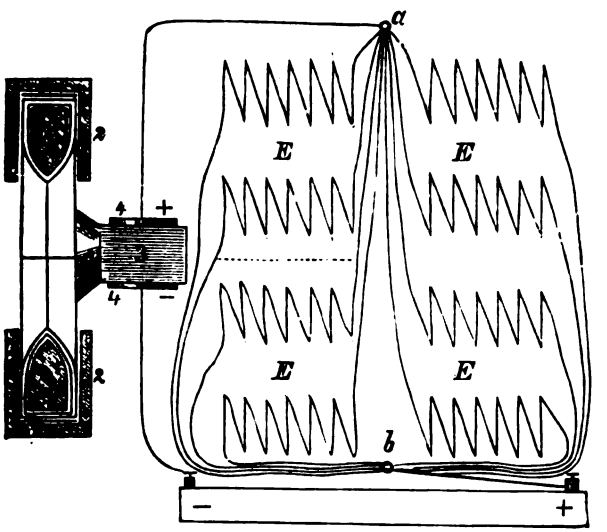


Fig. 240.—Diagram to illustrate the Theory of the Gülcher Machine.

Gülcher diminished the internal resistance of his machine as much as possible. Fig. 240 shows his machine in plan, and Fig. 241 in elevation. The arms of the electro-magnets (eight in number) are flat, and have wire ropes wound round them. The opposing similar poles are connected by ⊔-shaped pole-pieces (2 2, Fig. 240), which surround the ring (1 1), rotating between the magnet poles in such a manner that its sides as well as its edges are exposed to a powerful inductive influence. In order to utilise as much as possible the coiled wire, and to diminish as much as possible the heating of the machine, the cross section of the ring is wedge-shaped. The cooling of the armature is effected in a mechanical way also, for by the arrangement of the coils and construction of the ring, these and the pole-pieces form together a kind of ventilator. The pole-pieces are alternately magnetised with north and south magnetism, so that the machine has four magnetic fields, therefore four currents will be induced in the ring, which are first arranged in parallel order, and then

are made into one. It is clear that in this manner the resistance of the armature is considerably lessened, as the currents only flow through a small portion of the armature. The mode of applying the dynamo-electric principle is shown in Fig. 240. From the commutator 4, which is placed on the axis 3, the current flows towards *a*, and divides here, flowing through the parallel coils of the magnets E E; at *b* all the different branches again unite, and the total current flows

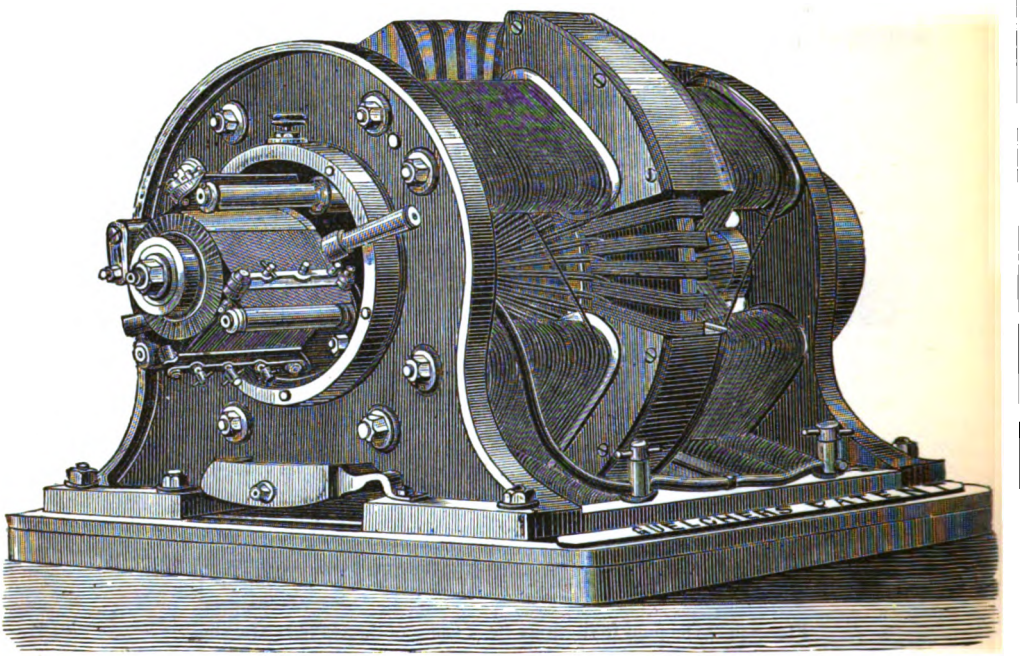


Fig. 241.—The Gülcher Machine.

through the binding screw + into the outer circuit, returning through the other or negative binding screw again to the commutator.

Fein's Machine.—The machine by Fein is shown in Fig. 242 in section. The core of the ring R consists of thin iron bands, which are insulated from each other, and together with coil terminals fastened to S S, which is attached to the axis *a a* of the machine. The wire terminals of the different coils lead to the sectors of the commutator C, upon which the brushes B slide. The inducing magnets M M′ are constructed and arranged in the same way as in the Gramme machine, only their pole-pieces A A are bent in such a manner that they surround the coils of the armature inside and out.

Heinrichs gave the core of his ring the form of a horse-shoe in order to increase the induction effects of the magnets.

The Brush Machine.—The flat ring machine by Brush differs in the construction of the commutator and armature from those already described, and as the Brush machine is typical of a large class of machines, it will be convenient to review the points in which it resembles or differs from them. For this purpose we shall follow the account of the machine which has received the approval of the Brush Company, and which was first published in *Engineering*.

The similarity of the Brush model to that of the Gramme machine consists in the shape of the annular armature, but it differs in the arrangement of the wire convolutions, and in the connections of the various divisions among

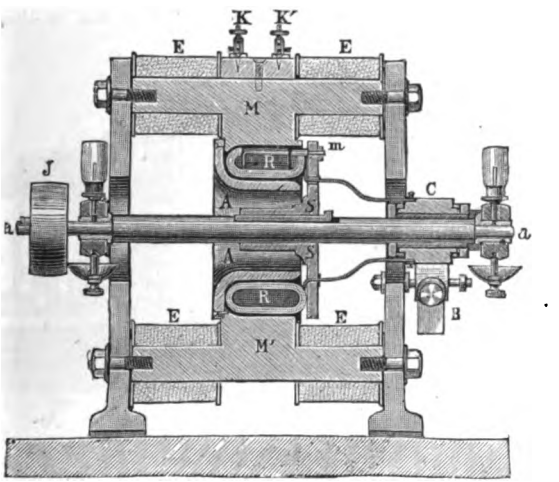


Fig. 242.—The Fein Machine.

themselves. The annular core of the Gramme armature is entirely covered by its bobbins, which are electrically connected with one another, so as to form one closed circuit. In the Brush machine the bobbins are separated by comparatively large sections of the core, which at those points are purposely thickened.

Again, its armature being a ring in form, not entirely overwound with coils, but having projecting teeth between the coils, is, as we have said, like the Pacinotti ring. But though it thus resembles Pacinotti's ring, it differs from it as much as that ring differs from the armatures of Siemens and Gramme; for in all those the successive sections are united in series all the way round, and constitute, in a sense, one continuous bobbin. But in the Brush armature there is no such continuity. The coils are connected in pairs, each to that diametrically opposite it, and adjacent coils are carefully isolated from one another. For each pair of opposite coils there is a separate commutator, so

that, for the ordinary ring of eight coils, there are four distinct commutators side by side upon the axis—one for each pair of coils. The brushes are arranged so as to touch at the same time the commutators of two pairs of coils, but never of two adjacent pairs; the adjacent commutators being always connected to two pairs of coils that lie at right angles to one another in the ring.

It is this difference from the Pacinotti and the Gramme rings which constitutes the similarity between the Brush armature and that of M. de Méritens; but the Brush machine differs in all other essential respects from the latter machine, in the disposition of its coils, in its method of connection, in the method and arrangement of the magnetic field, and in the continuous nature of its current. The Brush machine also differs from the Gramme generator in

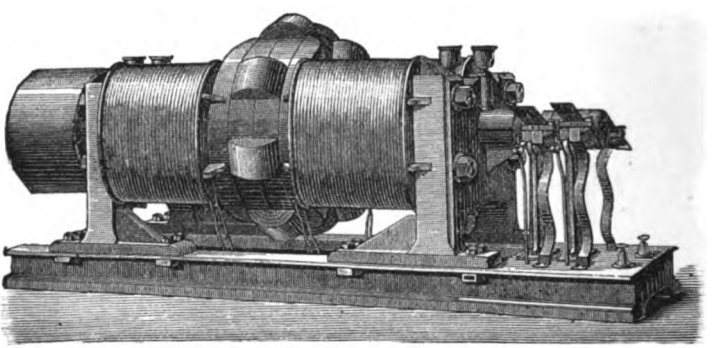


Fig. 243.—The Brush Machine.

the disposition of its field magnets, and the relative positions of the revolving helices and the magnetic field. We will now briefly describe these points in detail.

The ring is divided up into as many sectors as there are bobbins to be wound by a number of rectangular depressions or grooves; in these the coils of insulated copper wire are wound until the groove is filled up, and the flat converging recesses become flush with the face of the intermediate thicker portions or pole-pieces by which they are separated from one another. The intermediate thicker portions of the ring are grooved out by a series of deep concentric grooves, the object of which is partly to reduce the mass and lessen the weight of the revolving armature, partly for the purpose of ventilating the ring, and thus carrying away a portion of the heat generated by the working of the machine, but chiefly for the localisation and isolation of local currents generated by induction in the iron, and which would tend not only to reduce the efficiency of the machine by diminishing the magnetic capacity of the armature, but also to produce a heating of the ring, and therefore of the coils, whereby a portion of the current would be lost through their resistance being

increased. For a similar reason the periphery of the ring is grooved out deeply, so as almost to sever the ring; by this means all cross-currents are effectually cut off, and induction currents are compelled to flow in directions which are not detrimental to the efficiency of the machine. This again increases the area of radiating or cooling surface, and consequently helps to prevent the armature becoming over-heated (Fig. 244).

The two sides of each groove, and therefore of each coil of wire, are parallel to the centre line or radial plane of the coil, and, by the adoption

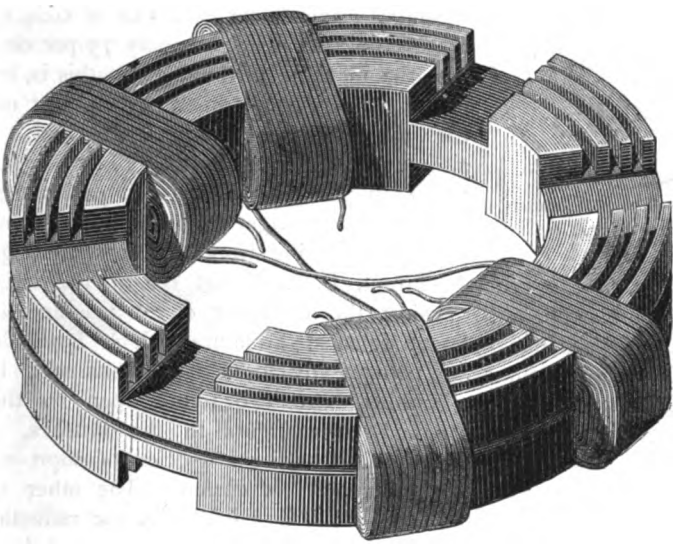


Fig. 244.—Armature of the Brush Machine.

of that form of bobbin, one of the practical difficulties in the winding of annular armatures of the ordinary form is avoided. All the coils are, like those in the Gramme machine, wound in the same direction.

The inner end of each of the coils is connected by a wire to the inner end of the corresponding coil, at the opposite end of the same diameter of the ring, and the outer ends of all the coils are brought through the shaft of the machine, and are connected to corresponding portions of the commutator, where the currents are collected by suitably-placed copper plates or brushes.

The commutator, which is attached to, and rotates with, the driving-shaft of the machine, consists of a set of separate copper rings or flat cylinders, of which there are as many on the shaft as there are pairs of coils on the armature, and each of these cylinders consists of two segments s s (Fig. 245), insulated from one another on one side of the shaft by a small air-space about one-eighth of an inch wide, and on the other by a piece of copper T, separated from the

segments by two smaller air-spaces. The object of the copper insulating piece (Fig. 245) is to separate the flat copper brushes or collectors, which press upon the periphery of the commutator, from the segments during the interval occupied by one pair of coils in passing through the neutral portion of the magnetic field; this occurs twice in each revolution of the armature, and therefore of the commutator. At the time when any pair of bobbins is in this way cut out of the general circuit, their own circuit is open, so that no current can circulate or be induced in them. By this most ingenious arrangement each pair of coils has a current passing through it for only 75 per cent. of the time the machine is running; to this is, in a great measure, due the very small development of heat in the working of the Brush machine, and it presents also another important element of efficiency, namely, that each pair of bobbins as it passes the neutral portion of the magnetic field, and is therefore incapable of doing work and contributing electro-motive force to the general current, is itself cut out of the circuit, and thus two causes operating against the efficiency of the machine are eliminated: the first is one common to most armatures which have, like that in the Gramme machine, a permanently-closed circuit, namely, that the currents generated in the bobbins have two routes open to them, the one through the conductors and commutators to the brushes, and the other through the idle bobbins, and thus, by a species of short-circuiting, robbing the external circuit of some of its current. The other cause of inefficiency, which is avoided in the Brush machine, is the reduction of its internal resistance by an amount equal to the resistance of two of the bobbins. As a certain amount of resistance is an item of efficiency when belonging to coils which are doing work and contributing electro-motive force to the general current, so does it become an element of inefficiency when belonging to coils which are idle, for in that case it diminishes the current supplied by the active coils, while at the same time contributing no current of its own in compensation.

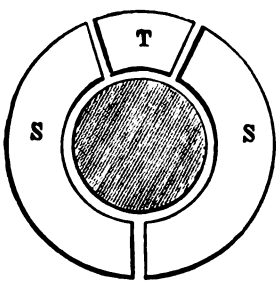


Fig. 245.—Brush's Commutator Ring.

Another important feature of the Brush machine is the arrangement of the magnets by which the magnetic field is produced, and by which the armature coils are, during their revolution, almost continually passing through a very intense magnetic field. Upon reference to Fig. 243, it will be seen that the armature ring is closely embraced on each side by the large horizontal electro-magnets, whose poles are expanded so as to be presented to three of the armature coils on each side, leaving one pair of coils free from their direct influence, and this is the pair which is passing through the neutral region of the magnetic field.

For the sake of adjusting the brushes, so as to make contact with the commutators at the most effective angular position with respect to the magnetic

field, they are mounted to the opposite ends of two rocking levers, which are capable of oscillating on the driving-shaft, and can be fixed in any desired position by means of a set screw, which clamps a stout wire rising from the base of the machine. The currents are conveyed from the brushes by wide strips of thin sheet copper, shown in the general view, and in order to allow for the variable distance of the free ends of the brushes from the base of the machine, they are made undulating or wavy, doubling up as the distance is shortened, and stretching out when it is increased.

The connections of the Brush machine may be seen in Fig. 246. The bobbins A_1 and A_5 are two opposite coils, connected to a slit collar. Each pair of opposite coils are similarly connected with their own collar, and all the collars are grouped

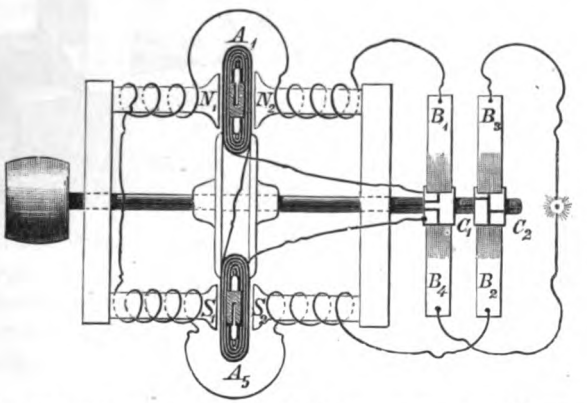


Fig. 246.—Diagram to illustrate the Theory of the Brush Machine.

in two sets, forming the commutators C_1 C_2; A_1 and A_5 are connected with the first collar, A_3 and A_7 with the second, A_2 and A_6 with the third, and A_4 and A_8 with the fourth. The collars 1 and 2 form the first, and the collars 3 and 4 the second commutator. The upper brush of the first and the lower of the second commutator lead to the arms of magnets, the others to the outer circuit. When the bobbins A_1 A_5 are passing between the poles of the magnets, the current passes as follows: Starting from the bobbin A_1, it passes to C_1, thence through the brush B_1 to the electro-magnets N_2 N_1 S_1 S_2 in order, and then back to B_2 and the commutator C_2, thence through the brush B_3 to the external circuit for lighting, thence to B_4 and commutator C_1 to A_5, and back to A_1.

The average total resistance of the sixteen-light machines, as now constructed, is about eleven ohms, to which the eight coils of the armature contribute about five ohms, that is, ·625 ohm each, and the magnet coils about six ohms, or 1·5 ohms for each helix; the resistance of the connections, conductors, contacts, etc., within the machine being inconsiderable.

The 16-light machine makes 770 revolutions per minute, and feeds 16 arc lamps requiring 15½ horse-power (1 h.p.=75 kilogrammetres); the E. M. F.=839 volts; and the strength of current, 10 amperes. Machines are also constructed of greater dimensions, for instance, for 40 lamps, requiring 35 horse-power.

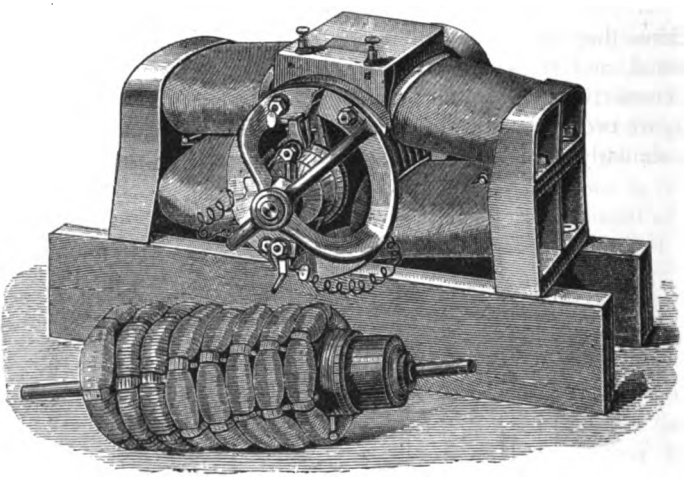


Fig. 247.—The Bürgin Machine.

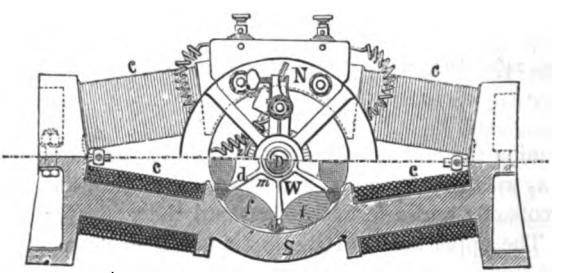


Fig. 248.—Section of the Bürgin Machine.

The Bürgin Machine.—This is the place to describe the Bürgin machine, the armature of which in form lies between the ring armature and the drum armatures to be subsequently described (Figs. 247 and 248). The form and arrangement of the electro-magnets are similar to those in Siemens' dynamo-electric machines. The armature, however, consists of a number of Gramme rings. The upper portion of the figure (Fig. 247) represents the elevation, and the lower portion the section of this machine. The framework consists of strong pieces of cast-iron, which form the cores of the electro-magnets,

and at the same time give stability and solidity to the machine. These cores are wound over with copper wire *c c*, except in the middle of the machine, where they assume the form of hollowed-out pole-pieces S N. Within the cylindrical space formed by the pole-pieces the armature W turns on a horizontal axis D, between the two magnetic poles.

The bobbins are spindle-shaped, as will be seen in the section at *ff*. Six of these bobbins are placed end to end round the shaft, so as to form a hexagon. About eight of these hexagons are arranged side by side on the shaft, the coils being fixed by the spokes *d* to the cylinder *m* that turns on the shaft D. The cores of the bobbins are formed of iron wire stretched over the ends of the spokes. The coils of one hexagon are placed a little in advance of those of the last, so that the vertices of the hexagons are situated on spirals. The coils are so wound on the cores that their outer circumferences form nearly arcs of circles.

The machine shown in the diagram has eight six-sided rings, *i.e.* = 8 × 6 = 48 coils. All the coils are so arranged that one wire terminal of each coil in the first ring leads to a segment of the commutator; the remaining ends of these coils are connected with the commencements of the nearest coils in the second ring; at the same time from these junctions wires lead to the segments of the commutator. The mode of joining the coils in the same ring is similar to that of the Gramme rings. The currents induced in the armature are conveyed to the external circuit by the brushes *z*, which are pressed against the commutator by means of springs. In consequence of the induction of one coil on the others, the rings in later machines have been alternated instead of being placed in a continuous spiral. In the most recent Bürgin dynamos, four hexagonal rings with a twenty-four part collector are used.

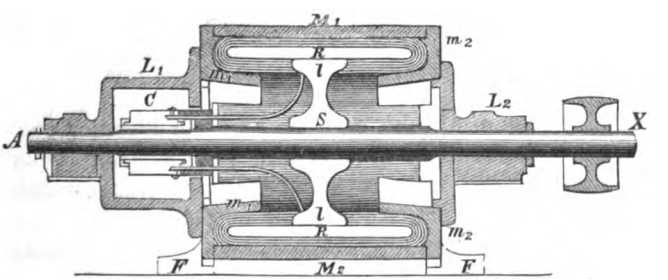


Fig. 249.—Section of the Schwerd-Scharnweber Machine.

The Schwerd-Scharnweber Machine.—The machine by Schwerd-Scharnweber, on account of its inner construction, must be classed with ring machines, and is shown in Figs. 249 and 250. The arms of the electro-magnets M are arranged horizontally, their poles are arched in the form of a semi-cylinder, and have the additional pieces m_1 m_2, consisting of soft iron, which partly cover the coils of the armature. By giving the magnet poles this shape the induc-

tion effects are increased, as in Fein's machine. The shaft A X has long bearings at L_1 L_2, which are well supplied with lubricators. At S a boss of brass is keyed upon the shaft, and to this the ring armature R R is attached by means of the four spokes *l*. The armature itself differs from the Gramme ring only in its breadth, which gives to it the appearance of a cylinder. The wire is coiled, and the wire terminals connected with the commutator C, in the same way as in Gramme's ring. When the machine is used for incandescent lamps the coils of the electro-magnets are arranged in shunt, whilst for arc lights the dynamic principle simply is applied.

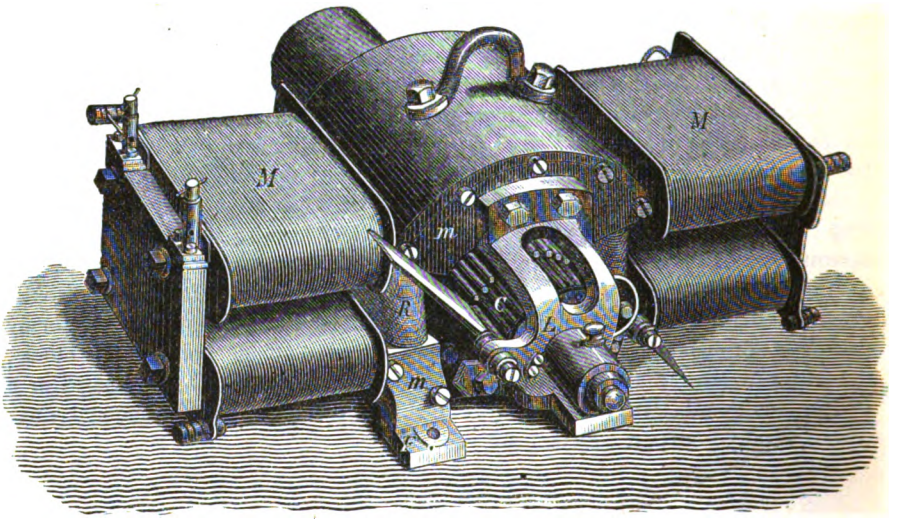


Fig. 250.—Schwerd-Scharnweber Machine.

The Hochhausen Machine.—The Excelsior Electric Company, of New York, construct machines on the Gramme principle, which find favour in America, and which have two special features. First, the frame and standards are utilised as much as possible in the production of the magnetic field; and, secondly, the armature is wound in sections, looped together and connected to a commutator, containing a segment for each section.

The framework is an upright case, consisting of two thick plates of iron, cast in one piece with the base and top, and bent or expanded outward at the middle, as if to make room for the armature. It is connected with the field magnets, somewhat in the manner of what is called a tubular magnet, and thus the magnetic effect produced by the coils on the outer frame, is added to that produced in the cores which are actually inside the coils.

The armature is of the cylindrical or widened Gramme ring form, much wider than usual, in this respect resembling the machine last described. The

core is made in sections, and thus the troubles incident to winding the coils on a continuous ring are avoided. This core is made of a number of thin iron ring-

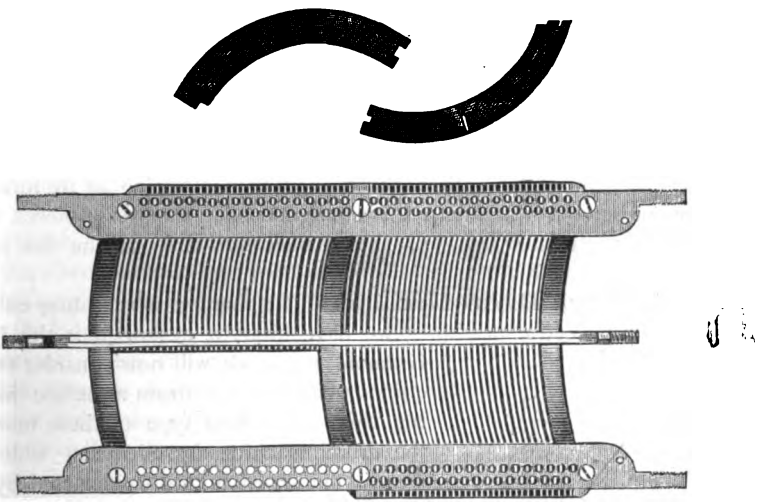


Fig. 251.—Core of Hochhausen Armature.

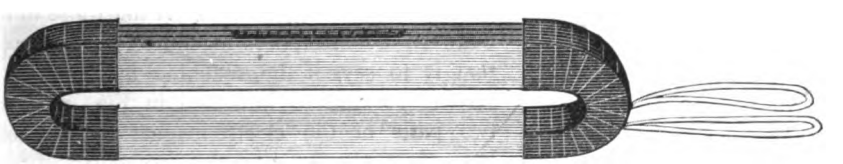


Fig. 252.—Single Coil of Hochhausen Armature.

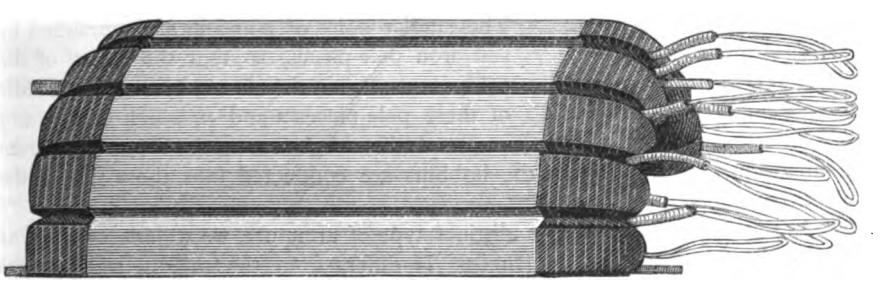


Fig. 253.—Half-Armature of Hochhausen Machine.

discs placed close together, each disc being made of four pieces. The quarter-discs are all punched alike out of thin sheet iron, about one-sixteenth of an inch thick. Their shape and method of fastening together are shown in Fig. 251.

A marked advantage in this manner of constructing the armature is that the sections or coils of wire, of which there are four on each quarter-disc, therefore sixteen on the entire ring, can be wound separately in a mould bobbin. Not only is the winding more easily done, but the chances of its being faulty are much diminished, and, above all, the insulation can be properly attended to. When the coils are thus wound, they are slipped on to their places on the quarter-ring; and the quarter-rings thus separately furnished are then screwed together as a whole. Fig. 252 represents one of the sections ready to be slipped on the armature core, and Fig. 253 one half of the core, with its coil sections in place. The core sections are connected to each other so as to form a ring by means of screws, which join the contiguous flat transverse pieces together. The holes for these screws are shown near the ends of the flat pieces in Fig. 251.

The Alteneck Drum Machine.—The characteristic feature common to all the dynamo-electric machines we have hitherto described is the Pacinotti-Gramme ring; we will now consider those machines which have a drum armature instead of the ring. The best type of these machines is the drum machine by Siemens, which has a drum armature of a kind constructed by Hefner von Alteneck, of the firm of Siemens and Halske. The electro-magnets E and E_1 (Fig. 254) are generally shaped and connected like those of the Schwerd-Scharnweber machine of Fig. 250, that is to say, if the machine is placed in a vertical position as indicated in Fig. 254, the two parts of the electro-magnet E form one horse-shoe magnet, and the two parts of E_1 a similar magnet having its N pole opposite the N pole of E, and its S pole opposite the S of E. The similar poles of E and E_1 are connected by soft iron pole-pieces, so that the poles of the compound magnet thus formed lie at the middle of these pole-pieces S and N, which in two arcs surround the drum armature. When the drum rotates, currents induced in the bobbins are conducted into the coils of the electro-magnets.

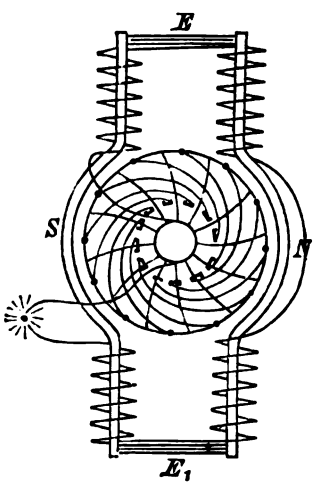


Fig. 254.—Diagram of Drum Machine.

As the Alteneck drum is a distinct type of armature, we will describe it, as we did the Gramme ring, at length. It differs from the ring in the fact that its constituent coils revolve about a diameter, and not about a line independent of themselves. In this respect it resembles the cylindrical armature of Siemens, but differs from the latter in the proportion of breadth to length, and in the fact that it is entirely wound with wire instead of being simply wound in the groove.

The drum armature usually consists of a hollow cylinder, which rotates with the shaft, and round which the wires are wound parallel with the axis of rotation. Travelling poles are induced in the cylinder during its rotation, as in the case of the Gramme ring, and, as the interval between the poles of the magnets and the armature is very small, the coils move in a field of high intensity.

To explain the mode of winding the wire of the drum, let us suppose the shaft that carries the iron core to have arranged round it near its end a number (8 for instance) of pieces of brass or copper properly insulated from the shaft, and from one another. These portions of brass will form the collector. Let us suppose the winding to begin from one of the segments of the collector. When the wire leaves the segment under consideration, let it run to the circumference on the front of the cylinder, then let it run parallel to the axis along the cylinder; again let it cross the back of the cylinder, and run along the opposite side, and finally let it be connected with another segment of the collector. This element of the coil will therefore be a rectangle, which will revolve about a diameter parallel to its longer sides; all these rectangles will cross at the same point in the side remote from the collector. During the rotation, one half of such a rectangular coil will be exposed to the influence of the north pole of the inducing field magnets, and the other half will be exposed to the influence of the south pole; in other words, the side *a b* will cut the lines of force between N N and S S in one direction, and the side *c d* will cut them in the other direction: accordingly currents, of opposite directions as regards space, will be generated in the halves of the rectangle. For instance, if *a b c d* (Fig. 255) be the rectangle, as in the diagram adjoining, in the lower half of the wire the current will flow from left to right, or from *c* to *d*, whilst in the upper half it will be directed from right to left, or from *a* to *b*, yet both together will form a current of the same direction *a b c d* round the rectangle. As the drum rotates, however, that half of the coil which at one moment was at the top, or point nearest the pole N N, will, after a semi-revolution, form the lower half, and be nearest to the pole S S. In other words, during every half-revolution of a coil, each half-turn of wire gets once into the position in which it cuts the lines of force at right angles, and once into the position in which it is moving parallel to the line of force. The current will be reversed immediately after the two sides of the coil have passed these neutral points, which are equi-distant from the north and south poles.

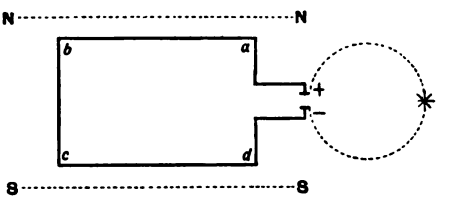


Fig. 255.—Principle of Drum-Winding.

We have next to consider how the elementary rectangles are combined. The winding is arranged so as to secure the following conditions: 1. A number of elementary rectangles are connected in series so as to form a continuous

coil, when they are so placed that the currents generated in them would have the same direction as regards the coil; (2) the ends of these coils rmed of elementary rectangles are connected with the collectors so as to conduct all currents of one direction simultaneously to one terminal, and all currents of the opposite direction to the segments diametrically opposite to the former. The coils are therefore coupled for quantity. The elementary rectangles of any coil are coupled *in series*, but the coils themselves are coupled *in parallel or multiple arc.*

In Fig. 229 we have already shown how it is possible to obtain a direct current by connecting the conducting wires with the respective segments. The method of conducting the current away is accordingly exactly the same in the alternate drum generator as that employed in the Gramme generator; that is, the conducting wires are always in contact with the two metallic segments of the commutator in which the currents meet, and through the revolution of the drum, all the commutator segments come into this position in turn.

This double arrangement of rectangles in series to form coils, and of coils in parallel or multiple arc, is brought about by means of the ingenious mode devised by Alteneck for connecting the segments of the commutator or collector at each instant. To trace the current through a set of elementary rectangles, which at a particular moment are connected in series, let us now refer to the diagrammatic representation in Fig. 256. While one half of each coil is approaching the south pole S, the other half of the coil approaches the north pole N, and therefore currents of opposite directions are induced in the two halves. But each coil bends back at O, the strands on one side running opposite to those of the first; it follows that the currents on the two sides, though opposite as regards space, have the same direction as regards the wire. Each side of the coils for every complete revolution of the drum approaches the north pole once and the south pole once, therefore currents of opposite direction will be induced in each coil successively, but these are turned in the same direction in the outer circuit by means of a commutator. There are four such groups of coils, indicated in Fig. 256 by the curves *c* 5 O 5′ *d*, *d* 7 O 7′ *e*, *e* 1′ O 1 *f*, *f* 4′ O 4 *g*. The thick lines *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h* represent the insulated portions of the commutator. The arrow at N shows the direction of rotation of the cylinder, the remaining arrows indicate the direction of the currents. The currents connecting the points 22′, 33′, 66′ and 88′ are left out, to simplify description.

Let us consider now the several coils and the induction phenomena that happen.

(1) The coils which start from 5′ and 7′ towards O approach the north pole N; they will have induced currents of a certain direction, indicated in the diagram as that from the points towards the commutator.

(2) The coils starting from 1 and 4 move away from the north pole. This would cause induced currents opposite in direction to the former, if the same face of the coil were presented to the pole; but the sides of the coils

that are presented to the north pole N have also changed. The currents, therefore, will again flow from the points 1 and 4 towards the commutator. An illustration may make this clearer. Assume a person to be approaching a looking-glass: the person and his image approach each other, *i.e.* they move in opposite directions, although both person and image move face forward. It follows that the direction of forward motion for the image is the direction of backward motion of the person in relation to a point outside. The same thing takes place with the currents at N. The coil is turned round as regards the pole, and the effects of the magnet above and below are relatively reversed. The effect of the double change is that the currents above and below N will have the same direction. Precisely the same kind of double change was explained in connection with the Gramme machine on page 247, both by Ampère's and by Maxwell's rules.

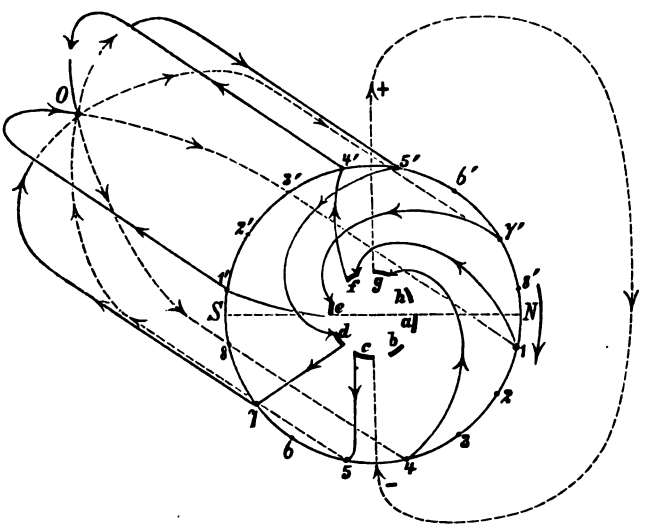


Fig. 256. – Diagram of a Drum Armature.

(3) The currents in coils starting from 5 and 7 flow opposite to the currents in 1, because they approach the south pole, whilst the currents in 1 approach the north pole; the direction, then, will be from the collector backwards.

(4) The coils, starting at 1′ and 4′, move away from the south pole, and their currents will therefore be oppositely induced to the currents in 5′ 7′; but the coils in 4′ are placed in the opposite position; it follows that the currents then of 4′ will have the same direction as those of 5 and 7, *i.e.* from the collector backwards. Currents then which have the direction "from the commutator" will be induced in the coils which start from 4′ 1′ 7 and 5; currents with the direction "towards the commutator" will be induced in the coils starting from 5′ 7′ and 4. A change of current takes place then between 5′ and 4′, also between 4 and 5, for every

coil that comes in this position. The straight line + − between these two points stands at right angles to the straight line N S. The arrangement of the commutator causes the currents to be turned in one direction in the outer circuit. Starting from the mark −, if we follow the direction of the currents over *c* 5 0 5′ *d* 7 0 7′ *e* 1′ 0 1 *f* 4′ 0 4 *g* to the mark +, we find all these turns are parts of the same closed circuit. The same holds good for the coils which start at the points 6′ 8′ 2 and 3 ; 3′ 2′ 8 and 6. The induced currents flowing through the former coils will be in the direction "towards the collector," while currents in the latter coils will have the direction "from the commutator." The connection of the several coils with the portions of the collector again give a closed circuit, which, starting at −, passes over *c* 3′ 0 3 *b* 2′ 0 2 *a* 8 0 8′ *h* 6 0 6′ *g*, and ends at +.

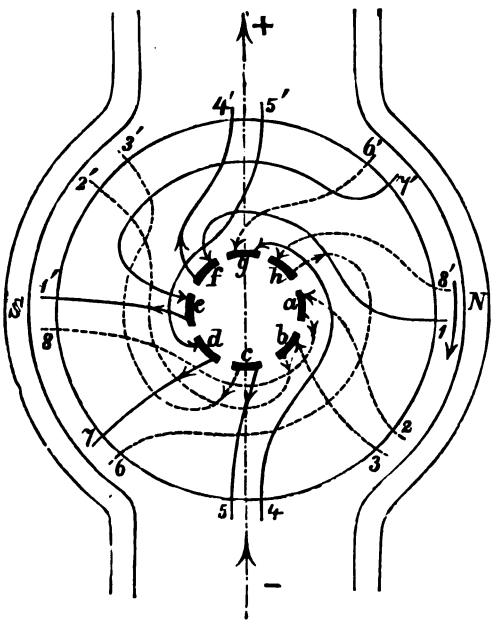


Fig. 257.—Diagram of Collectors.

Fig. 257 shows the collector, with its connections, but without the coils parallel to the axis. The different points have the same letters and numbers as in Fig. 256. The last-mentioned circuit is represented by the dotted lines in the figure. The commutator is so arranged that at *c* and *g* currents of the same direction meet, which would destroy each other if the wires + and − were not placed at those points so as to conduct the current into the outer circuit. The position of the brushes is regulated by the same considerations as have already been described in connection with the Gramme machine.

The simplest form of the drum armature when completed is shown in Fig. 258. An iron cylinder $s\,s_1\,n\,n_1$ is fastened upon the steel axis c c, which is movable in the bearings F_1 F_2. Insulated copper wire is wound round the cylinder longitudinally, the ends *e e* being carried to the commutator $p\,p_1$. N N_1 and S S_1 represent the sections of the magnetic poles. The magnetic poles are cylindrical arcs as regards shape, and surround the drum for more than two-thirds of its circumference. They influence the iron core by induction, and convert it into a powerful transverse magnet. The magnetic poles and the iron core form two powerful magnetic fields, oppositely polarised in the space between them, in which the coils rotate, whilst the cylindrical iron core may either be

fixed or movable. If, however, the coils are wound round the cylinder itself, the same deviation of the polarities in the direction of rotation takes place as was described in connection with the preceding diagrams.

From the description of the construction of the drum armature, it will easily be perceived that the inducing action of the magnets is, as we have said, more completely utilised in Siemens' generators than in Gramme's. For all parts of the wire coils of the armature move in magnetic fields, and no portion is situated inside the cylinder. Hence there is no idle wire except that which crosses the ends of the cylinder. In order to prevent the heating of the iron cylinder (which occurs in machines for generating large quantities of electricity, in consequence of the Foucault currents in the undivided metallic mass moving in the magnetic field), Siemens and Halske have constructed generators in which the iron core of the drum is fixed, and only the wire coils rotate in the magnetic field. In these generators the armature coils are wound

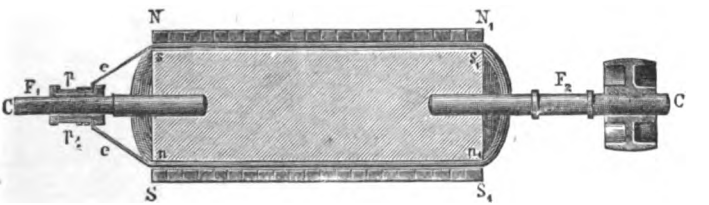


Fig. 258.—The Drum Armature.

on a drum consisting of a sheet of German silver, which rotates round the iron drum, at a little distance from it, and from the enclosing magnetic poles. The construction of such a machine is more complicated than that of a machine in which the core of the armature rotates as well as the coils, and owing to the small space between the poles and the drum, requires to be made with great exactness. The stationary magnets in all the larger drum dynamos obtain their currents from the armature; and in these machines, when the current is open, only so much power is required to drive the machine as will overcome the friction of the bearings; but when the circuit is closed—as, for instance, when a lamp is inserted—the coils are inductively affected by the small trace of residual magnetism in the stationary magnets, and currents immediately arise in these coils, and gradually increase as the speed increases. These currents further strengthen the electro-magnets, which in turn induce stronger currents in the armature, and so on until the maximum of power and current is reached.

The chief defects of the drum armature are—

1. The heating of the machine, particularly when the core of the armature rotates with the coils. The temperature of the armature in this case rises more rapidly than that of the field magnets.

2. Any irregularity in the outer circuit—as, for instance, in a lamp that is in

use—causes the formation of strong sparks at the brushes, and, therefore, a more rapid wearing away of the collector and brushes.

3. The convolutions made in the winding, according to the plan of Hefner von Alteneck, have, further, the disadvantage of being unsymmetrical, and, consequently, difficult to wind. This unsymmetrical form also favours the production of sparks at the collector, in consequence of the absence of electrical equilibrium on opposite sides of the armature, or in the bobbins connected by means of the segments of the collector. This defect, however, has been remedied lately by the adoption of a plan of winding, invented by Fröhlich, which secures that the connections of the bobbins with the segments of the commutator shall be symmetrical.

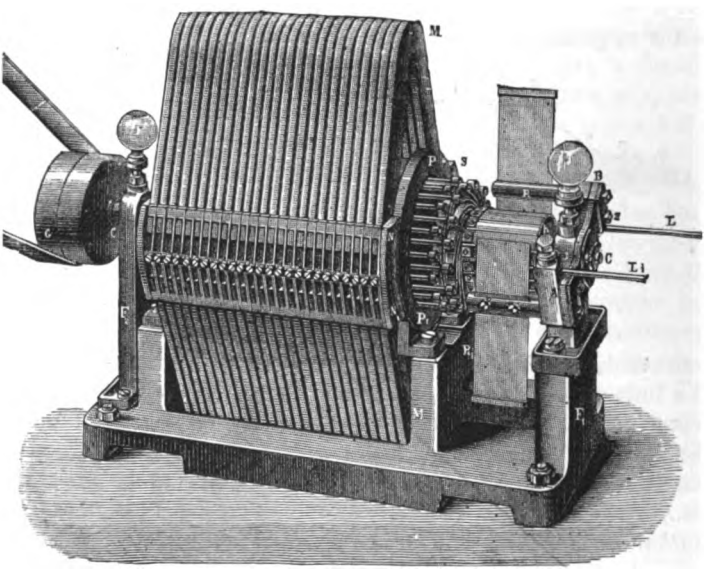


Fig. 259.—Siemens' Drum Machine.

Siemens' Drum Dynamo.—Drum machines have been constructed, of different shapes and sizes, by the firm of Siemens and Halske. The one represented in Fig. 259 is intended for a motor. The vertical stands F, F_1 carry the bearings for the shaft, $c\ c_1$, which carries the drum. The steel magnets M M are shaped like the letter **V**, but have pole-pieces of the cylindrical arc form already described. These magnets are so arranged that all their north poles at N N and their south poles at S stand diametrically opposite. Such an arrangement produces magnetic fields of great intensity, and having powerful induction effects upon the rotating drum. The commutator shown at $p\ p_1$ is made of brass

bars on a cylinder of insulating material; it is, therefore, of the split tube kind. It collects the currents of the same direction, and conducts them by the brushes $R R_1$ into the outer circuit $L L_1$.

For lighting or electro-chemical purposes, and for the transmission of power, electro-magnets are used instead of the steel magnets. The machine shown in Fig. 260 is intended for lighting purposes. There are seven powerful flat electro-magnets on each side, so arranged that their north poles face one another. The similar poles of the two magnets are connected by arched pole-pieces.

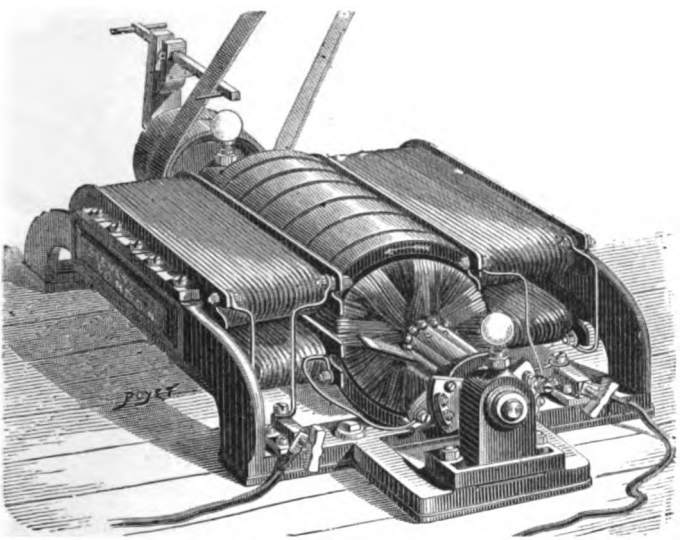


Fig. 260.—Siemens' Machine for Lighting.

The seven iron bands which are arched round the drum cause two-thirds of the bobbins to be exposed to induction at the same time. The current induced in the coils of the drum flows through the right-hand brush of the current collector, from there into the coils of the electro-magnet, and then through the right-hand binding screw into the outer circuit, then through the left-hand binding screw into the coils of the magnet, and thence back again into the coils of the drum. This machine is constructed in different sizes; the model having the mark D1 produces, for instance, a light=12,000 normal candles, by 500 revolutions per minute, worked by seven horse-power; its length is 1·21 metres, breadth 0·86, height 0·35, and it weighs 500 kilogs. Fig. 261 represents a machine generally used for the separation of metals from their solutions; that is to say, for electrolysis. As has been mentioned already, for such purposes electricity of large quantity, but not of high potential, is required.

The coils of electro-magnets and drums will therefore have to be constructed of large cross section, but fewer turns: this corresponds to the use of batteries of a few elements having large plates. The figure shows that each arm of the electro-magnet has only seven turns; these, however, do not consist of wire, but of copper rods, having a cross section of thirteen square centimetres. The coils of the armature also consist of copper bars. The junctions are not soldered, but screwed together, asbestos being used for insulating. Machines like these have been used for years in the Royal mines at Oker (Hartz

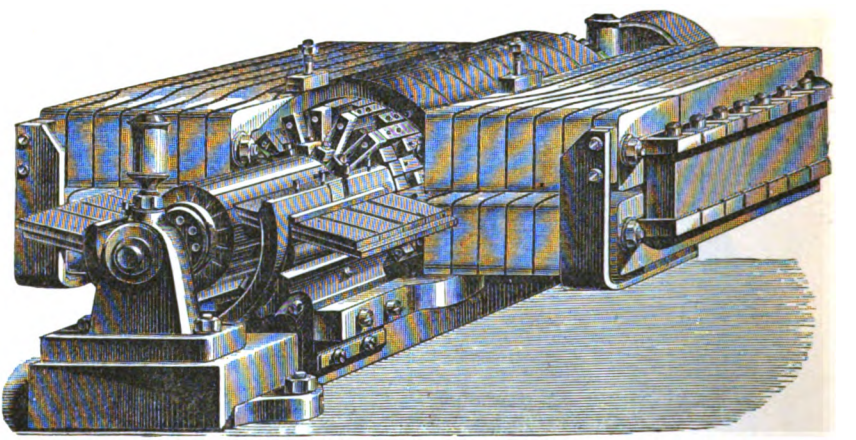


Fig. 261.—Siemens' Machine for Electrolysis.

Mountains); they separate daily from five to six hundred-weight of copper, requiring from eight to ten horse-power.

The Edison Machine.—Just as the ring machines are distinguished by the use of the Gramme ring, so also the Siemens armature is the characteristic feature of a series of machines more or less modified in other respects. Fig. 262 represents the dynamo-electric machine by Edison, intended for sixty incandescent lamps of sixteen candles each. Here the field magnets differ in shape from those of other machines. They are of great length, in form of iron bars united by pole-pieces of soft iron, and weigh several tons. In the cavity between the pole-pieces revolves the cylinder or drum armature. This machine has several contrivances to prevent waste; the brushes are numerous to prevent sparking; the interior of the armature is in form of thin discs, to avoid induction currents. The field magnets are placed vertically; their pole-pieces consist of an iron block, which is hollowed cylindrically. In this space a cylindrical armature rotates.

Fig. 263 represents a machine for 250 lamps equal to sixteen candles each, and Fig. 264 represents the thousand-light machine used for the lighting of stations.

This steam dynamo, as Edison calls it, consists of a horizontal steam-engine of 125 horse-power, and the dynamo-electric machine, which are both fastened upon one platform. The inducing electro-magnets consist of eight cylindrical arms, coiled with insulated wire, and two massive cast-iron pieces, which serve as poles. The latter are hollowed out so as to provide a space in which the armature may rotate. The length of the arms of the electro-magnets is 2·4

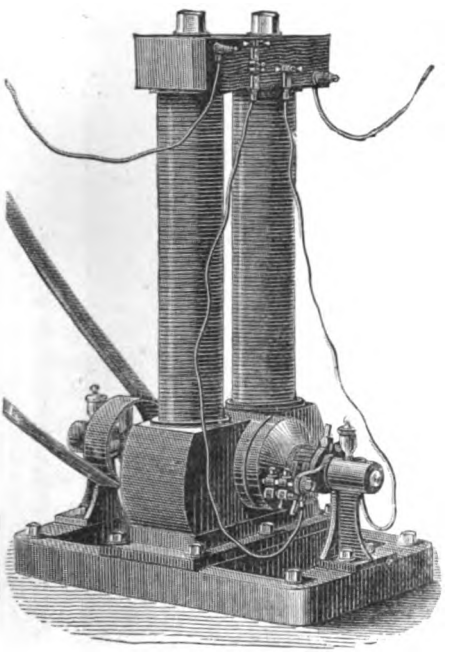


Fig. 262.—The Edison Machine.

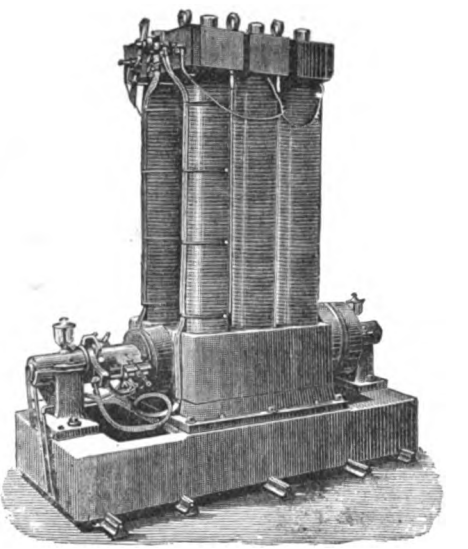


Fig. 263.—Larger Edison Machine.

metres; they are fastened horizontally, and their coils form part of the circuit of the machine. In principle the armature is a Siemens cylinder, with Gramme's method of connecting the wire terminals. The turns are parallel to the axis of rotation of the cylinder, but instead of wires, are composed of copper strips of trapezoid cross section. The different strips are insulated from each other by a kind of blotting-paper specially prepared. To the shaft in front of the cylinder are fastened as many copper discs as there are copper strips on the surface; every two diametrically opposite copper strips have their ends connected with a copper disc in such a manner that all the copper strips, discs, and connections form a continuous coil round the cylinder. This will be shown more clearly by the help of Fig. 265. The wooden cylinder B is fastened upon the shaft A, to carry the cylinder D, made of soft iron (being the core of the armature); S S are

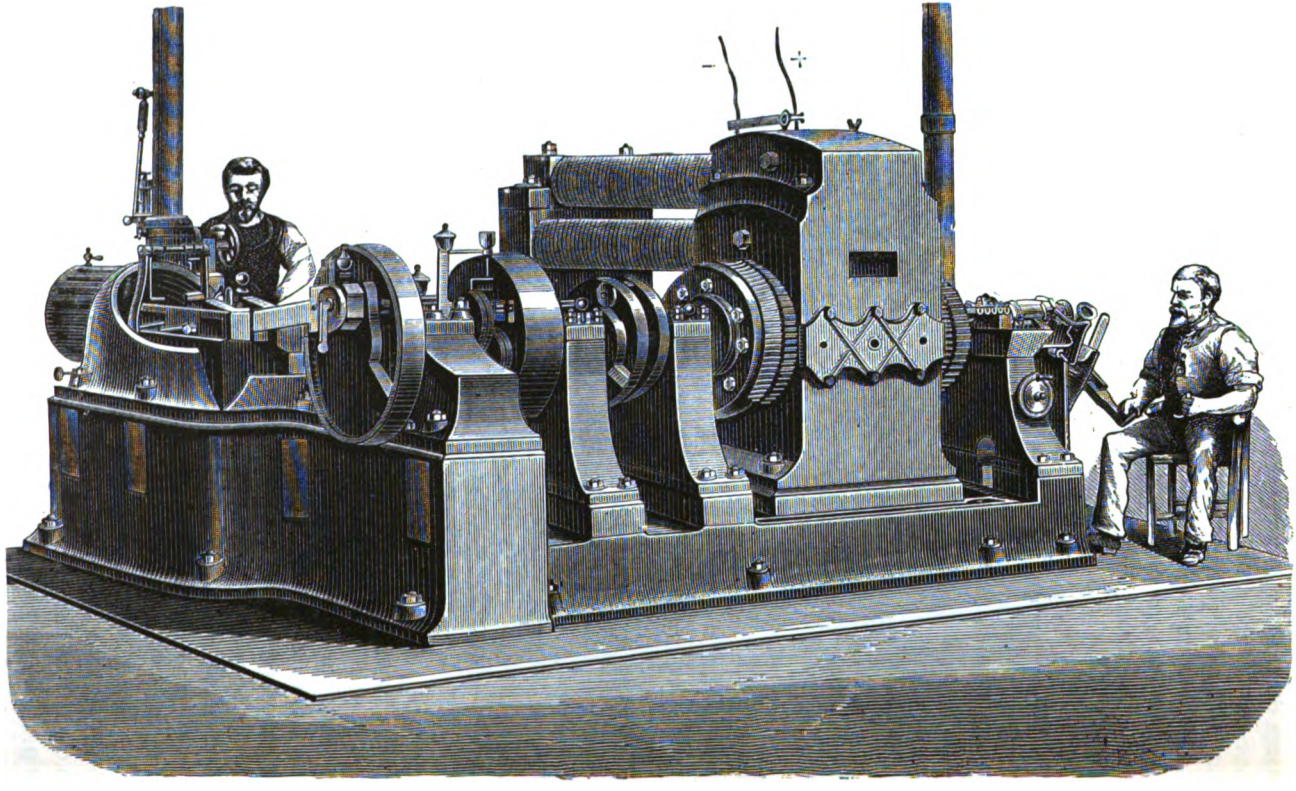


Fig. 264.—Edison's Thousand-light Machine.

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the copper strips, of which the large machine has 146, and L L the copper discs; C is the current collector, or commutator, constructed on Gramme's principle. By this arrangement the resistance of the armature, and especially that of the inactive parts near the front sides of the cylinder, is reduced to a minimum, and

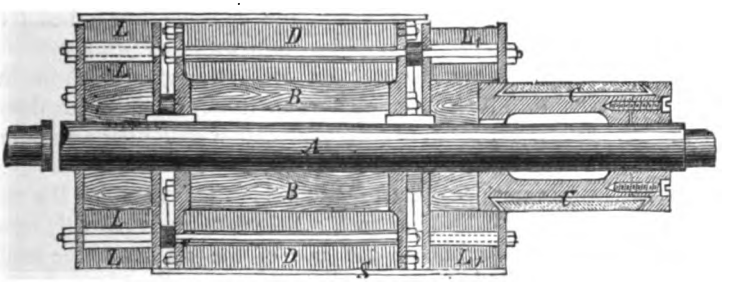


Fig 265.—Edison's Armature.

the connection of the several coils is brought about without complicated turnings of the wire. The strips measure 1·05 metres, of which one metre is directly affected by the magnet poles. The total weight of the machine is over 17 tons; of this, 10 tons go to form the enormous electro-magnets, and 2·5 tons to the armature. This machine feeds 1,000 incandescents of sixteen candles each, on Edison's system. The shaft of the motor is connected by couplings to the armature shaft. Such machines are in use at the Central Station, New York, and supply a whole district with electricity.

It can now be seen that although Edison's armature acts like that of Siemens, it differs from it in being more simple in construction and winding. The small

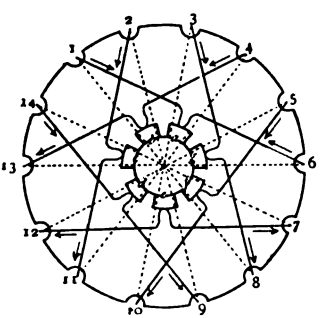


Fig. 266.—Edison's Winding.

machines have for a winding well-insulated copper wire in place of copper bars. The diagram, Fig. 266, taken from the drawing of one of Edison's patents, will serve the purpose of explaining his system of winding. There

are fourteen divisions, or seven crossings or loops, when there are seven segments in the collector. The number of segments in the collector in Edison's machines is always uneven; the new large machines have forty-nine. Consequently when the brushes bear on the collector diametrically opposite to each other, the sectors do not pass simultaneously from under them. While one brush bears on the centre of a sector, the opposite brush bears on two sectors, and so short-circuits the two bobbins connected therewith.

It will probably make the construction still clearer, and show in what respects the bar armature differs from the drum, if we conclude our description by giving, in Mr. Edison's own words, his explanation of the bar armature which he first made:

"In that class of magneto- or dynamo-electric machines in which the revolving armature is composed of a cylindrical core, whose surface is partially or entirely covered with coils wound parallel to the axis of the armature, the coils cross each other at the ends, so that there is a large mass of wire upon the ends useless for the purposes of generation, while interposing unnecessary internal resistance in the machine, and at the same time being in a position which favours the excessive accumulation of heat. These masses of wire, crossing each other at the ends, render repairs to any coil exceedingly difficult, for the repair of any one coil involves the unwinding of such coils as may overlap it upon the ends.

"One object of this invention is to construct the revolving armature so that these defects are remedied, to which end this portion of the invention consists in fixing upon insulating discs, which are to be secured to the ends of the armature, metal plates, or bars, corresponding in number to the number of coils or conducting bars; or if a coil be considered as consisting of the two active bars or assemblages of wires exactly opposite to each other upon the face of the armature, then the number of plates is double that of the coils. These bars are arranged upon the discs as spokes from a hub, radiating from the centre, and may be termed the 'radiating' plates or bars. These plates or bars are electrically joined in pairs or couples, by circular metallic conductors, permanently fixed upon the insulating discs, care being taken to insulate these circular joining conductors from each other. This arrangement of radiating bars or plates and joining conductors takes the place of the wires which formerly crossed the ends. The radiating plates or bars are provided at their outer edges with recesses, in which the active generating metal, whether in the form of wires, strips, ribbons, or bars, may be secured by soldering, or by screws, or they may be secured together in any other suitable way.

"The construction of revolving armatures, as ordinarily practised, especially in the case of very large machines, involves the use of a large amount of insulated wire. This is expensive, and besides takes up room, and allows of the accumulation of heat, owing to the non-conductor forming the insulation, to remedy which is another object of this invention. For this end I use rigid naked bars, or wires, of proper material, which are so disposed about the armature that each

is separated from the others, there being between them an insulation, partly of mica and partly of air, which suffices in practice for insulation, and, in addition, allows such access of air to all the active parts of the armature that danger of heating thereof by accumulation is greatly lessened.

"In dynamo- or magneto-electric machines, it is often desirable to give considerable electro-motive force to the generated current, while at the same time there is maintained a low degree of internal resistance of the machine. Another part of the invention relates to the accomplishment of this, and consists in so arranging the coils or bars and the commutators that all the coils or bars are always in circuit, so that an electro-motive force due to the entire length

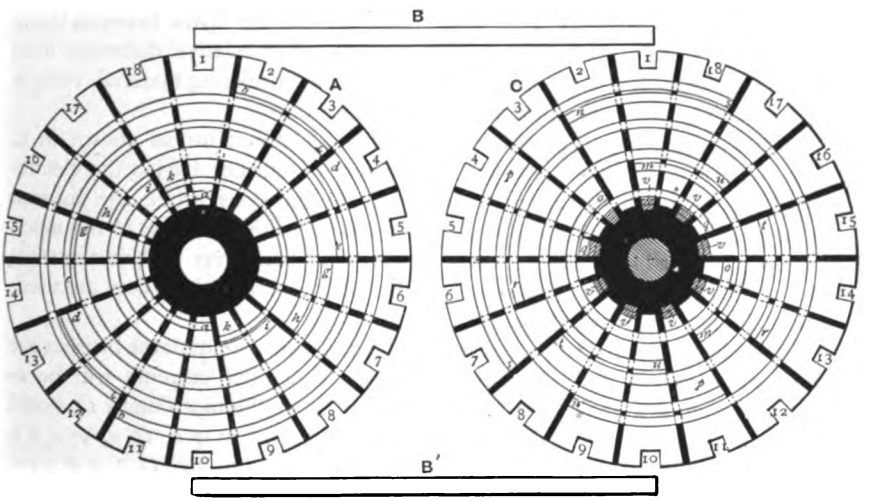


Fig. 267.—Edison's Armature.

of all the coils is obtained, and at the same time that part of the conductors which does not set up an electro-motive force within the circuit is made of lower resistance by means of the circular and radial bars or plates at the ends than the portion in which the electro-motive force arises.

"The entire invention may be carried into effect by means substantially such as shown in the drawing (Fig. 267), wherein C is the commutating end, and A the other end of an armature.

"Upon suitable insulating bases, circular in form, the radial metal plates numbered 1 to 18 in A and C are secured, insulated from each other, as indicated by the blank space between them. Upon A the circular plate or bar *a* connects 1 and 10; *b*, 2 and 11; *c*, 3 and 12; *d*, 4 and 13; *e*, 5 and 14; *g*, 6 and 15; *h*, 7 and 16; *i*, 8 and 17; *k*, 9 and 18. Each of these bars is insulated from the other, and from all the plates excepting those which it is designed to connect. It will be noticed that upon this end the circular bars connect

exactly opposite coils, as would the wires ordinarily used. Upon the commutating end C the arrangement is somewhat different. Upon it 1 and 12 are connected by *m*, 2 and 9 by *n*, 3 and 14 by *o*, 4 and 11 by *p*, 5 and 16 by *q*, 6 and 13 by *r*, 7 and 18 by *s*, 8 and 15 by *t*, 10 and 17 by *u*. These bars are insulated, as before stated in the case of A. Upon the commutating end the odd-numbered circular bars are bent outwardly, at a right angle, at their inner end, the bent portions *v v* being secured to a hub, and forming the commutator. To these end discs thus constructed are secured wires, ribbons, or bars, in any suitable manner, forming with the radial and circular plates the coils.

"For large machines I prefer to use naked bars of copper, B B', which are secured in the recesses shown in the outer edges of the radial plates. They will be sufficiently insulated from each other by the air space between them. If bars are used not sufficiently rigid to preserve their relative distances from each other throughout their length, stays or blocks of insulating material, such as mica, may be placed between them at proper intervals.

"By the arrangement of connections and the commutator, as shown in C, all the coils are constantly in circuit, the generated current having the electromotive force of a coil of the total length of all the coils, while the internal resistance is kept low by the lessening of resistance in the ends due to the much larger mass of conductor in section of plates and bars over that of the wires ordinarily used, while the resistance of the active parts, when bars are used, as described, is also greatly lessened.

"Supposing the parts are in such position that the commutator brushes are in connection with 5 and 15, the path of the generated currents will be as follows: starting, say, at the brush on 5, the path in the machine to 15 would be, for one portion of the current, *viâ* 5 *e*, 14 *o*, 3 *c*, 12 *m*, 1 *a*, 10 *u*, 17 *i*, 8 *t*, 15; and for the other portion, *viâ* 5 *q*, 16 *h*, 7 *s*, 18 *k*, 9 *n*, 2 *b*, 11 *p*, 4 *d*, 13 *r*, 6 *g*, 15, thus including every coil."

One of the most common defects of large machines is the generation of sparks near the commutator, causing them to wear out. In Gramme's arrangement of the current collector the following takes place: The spring *f* (Fig. 268) reaches the metal strip 2 before it has entirely left 1, which causes the coil *s* to become short-circuited through 1 2 and *f*. If now the difference of potential between the two ends of the coil *s* is considerable, the short circuit will be brought about before the strips 1 and 2 are connected by *f*, because self-discharge in shape of a spark takes place. Edison has a contrivance for his large machines which prevents the interruption or break of current, and considerably diminishes the generation of sparks. In Fig. 269, a_1 a_2 a_3 indicate the insulating strips, b_1 b_2 b_3 the metal strips of the commutator A. The metal strips have not the same breadth throughout, but have the shape shown in the figure. Over the wider portions of the metal strips slide the brushes *d d*, and over the smaller portion, separated from the latter, slides the brush *e*. The current-breaker B rotates upon the same axis as the current-collector A. The metal strips c_1 c_2, etc., upon B correspond with the small portions b_1 b_2

upon A (which allows B to be removed from the machine). Over the metal strips of the current-breaker B slide the two brushes h_1 h_2, which are separated from each other. Brush h_1 is connected with the brushes $d\,d$, and h_2 with the brush e. The brushes e h and h_2 reach a little higher than the brushes $d\,d$. When the machine is in motion, and A and B rotate with a uniform velocity, the following takes place: Every time the brushes $d\,d$ rest upon one of the metal strips b_1 b_2 of A, the brushes e h and h_2 will rest upon insulating strips. The latter brushes, therefore, have no active share in the conduction of the current, which is brought about in the usual manner through the brushes $d\,d$.

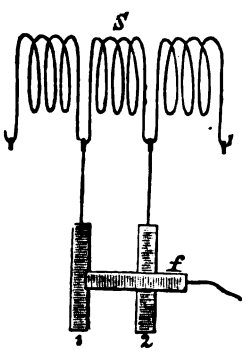


Fig. 268.—Gramme's Arrangement to Prevent Sparking.

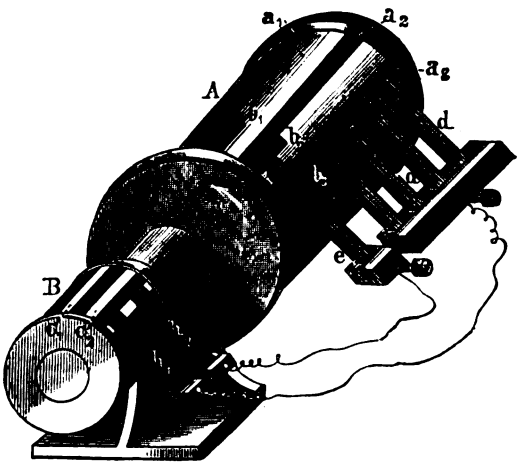


Fig. 269.—Edison's Commutator.

However, before the brushes $d\,d$ leave the metal strips b_1 b_2, the brush e comes into contact with them; at the same time the brushes h_1 and h_2 come upon a metal strip of B. The current flows now through the brushes e and h_2, reaches the metal strip upon B, from this passes through the brushes h_1 and $d\,d$, and thence to the outer circuit. This passage is open to the current as long as the brushes $d\,d$ slide upon an insulated strip; when they slide upon metal strips the brushes h_1 h_2 reach insulating strips, and the connection between h_1 and h_2 is broken. In this manner the current in the outer circuit is made continuous, short-circuiting of a coil is prevented, and the production of sparks is reduced to a minimum.

The insulating material used by Edison between the sectors of the collector has the advantage that it wears away at the same rate as the copper sectors; consequently the collector wears truly, without longitudinal furrows, flutes, or channels, and runs with but few sparks.

The various sizes of machines made by Edison at present are tabulated as follows:—

Type.....	E	Z	L	K	C	H
Weight in kilogrammes	290	1,230	2,600	3,300	30,000	3,600
Horse-power	2·5	8	18	32	125	65
Rotations per minute	2,200	1,200	900	900	350	1,100
Capacity, 16-candle lamps	17	60	250	250	1,200	400
Volts of tension.....	110	110	110	110	110	110
Number of magnet limbs.....	2	2	6	6	12	6

The above figures show plainly the advantage of using large machines, to which much power can be applied.

Edison's dynamos all have massive pole-pieces and heavy yokes connecting the iron cores. All his earlier field magnets were very long, and he at first thought that the high efficiency of the Edison dynamos was due to the use of these large masses of iron in the construction of the field magnets. This has been regarded by others as a disadvantage on account of additional weight imparted to the machine without proportionate increase in the intensity of the magnetic field, and some maintain that the same intensity can be obtained with magnets of half the length; but according to Edison's experience, this is not the case. According to his view, if the mass of iron be reduced, a stronger current, and therefore more energy, is required to raise the field to the desired intensity, and this additional amount of energy must be continually supplied as long as the machine is run. In the other case, the additional expense for a cheap material is only incurred once. This view seems to be justified to some extent by the fact that the Edison machines for efficiency rank among the best. But Mr. Edison has recently found it advisable or convenient to reduce the length of the cores of the field magnets of his machines, and has also changed the shape of the pole-pieces so as to avoid sharp corners. Sharp angles and corners in magnetic masses are unfavourable to a proper distribution of the lines of force in the magnetic field.

Weston's Machine.—Weston's machine (Fig. 270) shows in its general form a certain resemblance to Siemens' machine, but differs from the latter chiefly in the construction of the armature. The iron core is constructed in the following manner: Thirty-six iron discs are fastened upon the rotation axis, each disc having sixteen teeth cut in it. Sixteen pieces of square section are laid across these discs, as shown in Fig. 271, and upon these the coils are arranged. The connection of the commutator and the wire ends is the same as in Siemens' machine. The segments of the commutator, however, are not parallel to the axis, but arranged spiral-shaped, and insulated from each other by layers of air. This arrangement has the advantage of bringing several sectors at the same time in contact with the brushes, and thus producing a uniform flow of the current. The electro-magnets consist of several cast-iron

rods, which are fastened horizontally to the vertical supports. The ends facing each other are connected by means of bent wrought-iron bars; but the two end couples have, instead of the bent bars, elliptically-shaped iron pieces. According to Weston, the uniformity of the current is greatly increased by this arrangement. The peculiarly formed iron core, the spaces between the magnets, and the perforated stands, together secure very good ventilation.

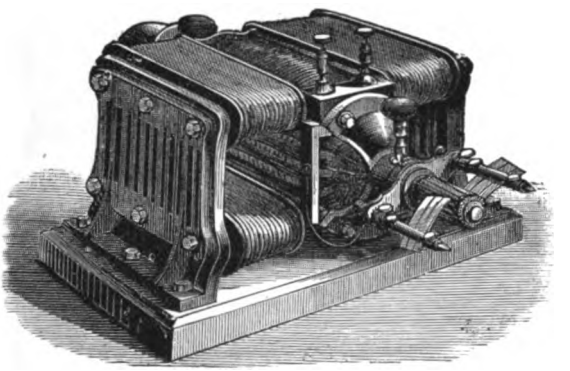


Fig. 270.—The Weston Machine.

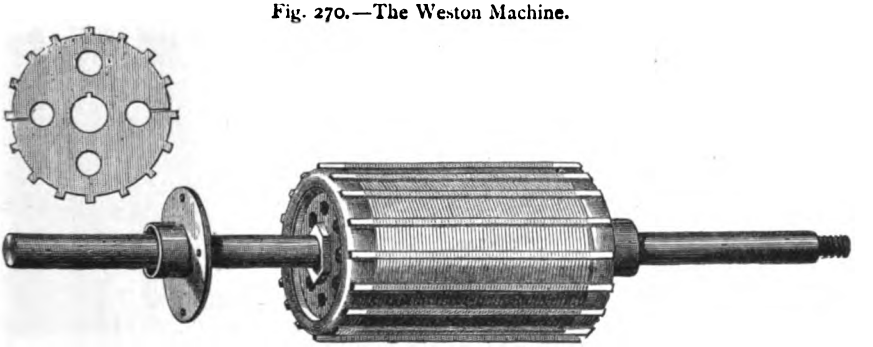


Fig. 271.—The Weston Armature.

This machine has undergone many alterations; the latest shape given to it is shown in Fig. 272. Here the spiral arrangement of the copper strips of the commutator has been abandoned, as it secured uniformity of current only by loss of intensity. To prevent as much as possible the production of sparks, the commutator received a far greater number of metal strips (as many as 140 being used), so that each strip corresponds to the point of junction of the wires of two coils. By this arrangement the number of the groups of the armature is increased, and consequently the difference of potential at the ends of each coil diminished. The commutator is fixed so that in case of damage it can easily be replaced. The sliding springs consist of elastic copper plates, having several

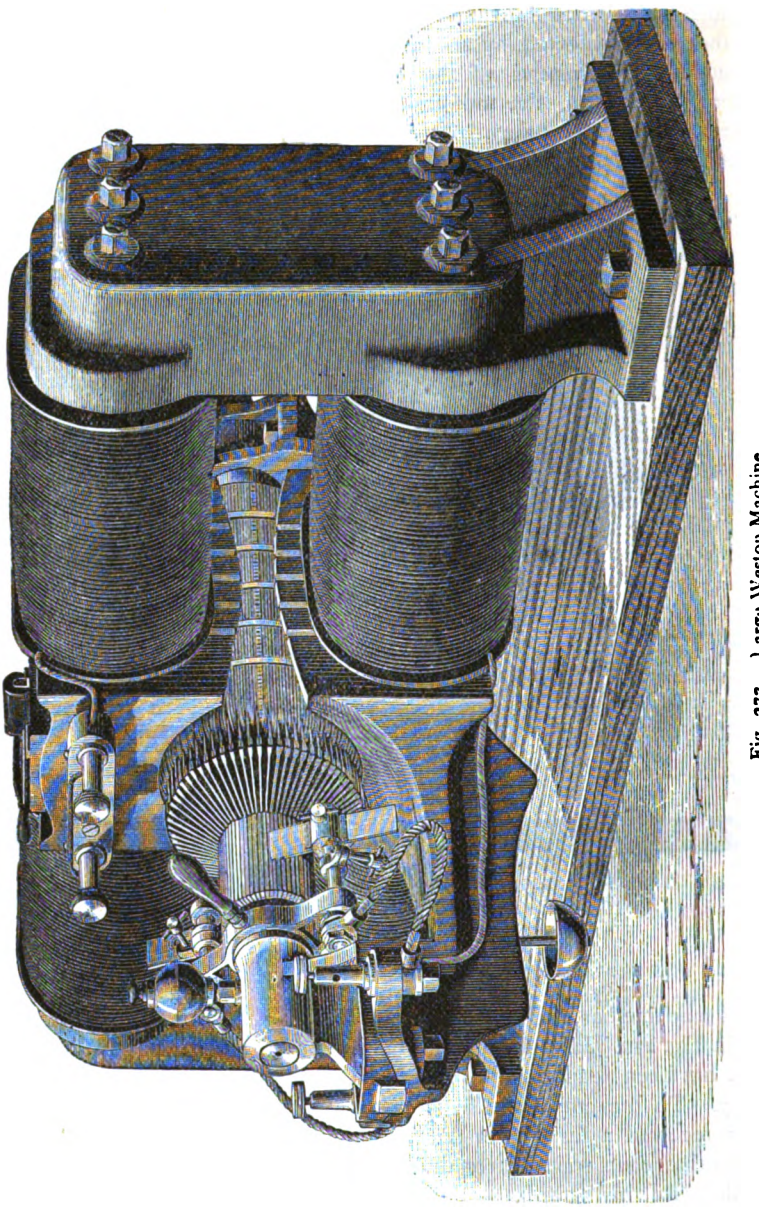


Fig. 272.—Large Weston Machine.

slits in them. In large machines of this kind the currents of the electro-magnet are shunted from the principal circuit; such a machine feeds twenty arc lamps, makes 900 revolutions, and requires fourteen horse-power. In machines required

to feed a greater number of lamps, Weston uses a special method for coiling and connecting the wires of the armature. When we were explaining the action of Edison's commutator, according to Gramme's method, we pointed out the danger

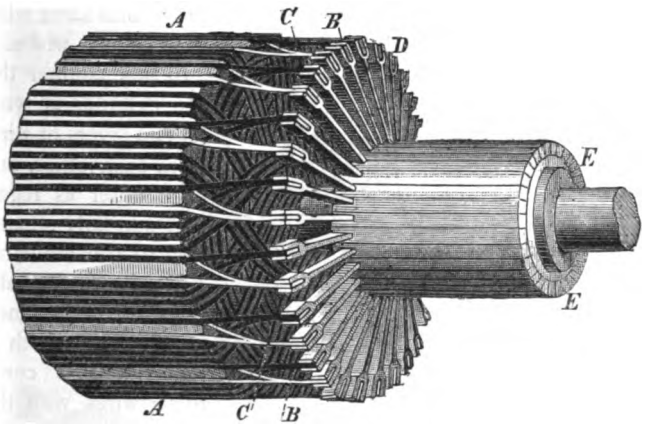


Fig. 273.—The New Weston Armature.

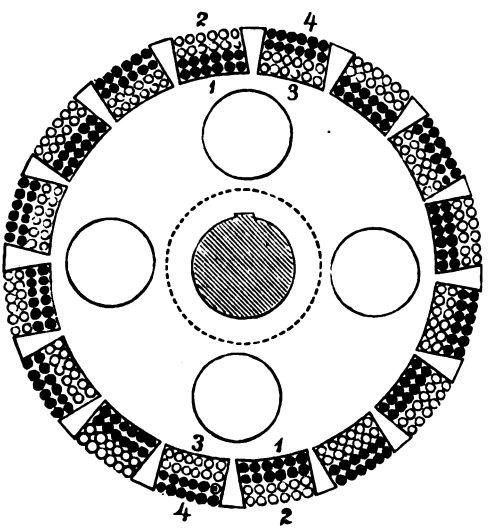


Fig. 274.—Section of the New Weston Armature.

of the armature coils becoming short-circuited. It is to avoid this that Weston uses his spiral method for coiling. Fig. 273 is a representation of the armature, Fig. 274 a cross section in the direction A A. The layers of wire in the sixteen grooves of the iron core are divided into two sets, indicated by black

and white in the figures. The commutator strips E E are also double. The wires are arranged in the following manner: First one groove of the cylinder, and that diametrically opposite to it, are wrapped with a layer of wires (drawn black in Fig. 274, and indicated by 1_1 1), then another layer of wires, perfectly insulated from the first, is added (left white, indicated by 2_1 2). The same wire is carried into the grooves nearest, and forms the lower layer 3_1 3, left white. The wire left at 1_1 1 is used to form the upper layer of 4. In this manner the whole of the cylinder is wrapped with its two layers of wire, insulated from each other, but equal to each other as regards length, and similarly situated in relation to the inducing magnets. Fig. 273 shows that the black layer of wire C and the white layer B follow each other alternately. The connection of these wires with the commutator is brought about by means of the pieces D. That by this arrangement and mode of connecting the several groups the danger of short circuit is obviated may be shown by Fig. 275. If segments 1 2 or 2 3, or any other segments of the commutator following each other, be connected, a short circuit will not be produced, as in the Gramme ring. To obtain this result it is not absolutely necessary to adopt the above method of winding the wire round the cylinder, provided attention is paid to the principle that two adjacent segments of the commutator shall not be connected with the ends of any one group that is closed in itself. The wire turns of the whole armature may be divided into more than two independent circuits, and this arrangement might be more advantageous with very large machines, producing currents of high potential.

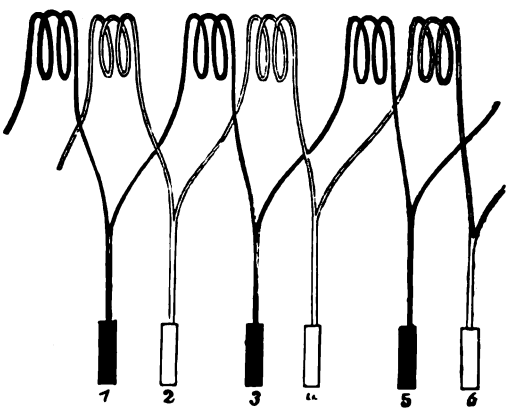


Fig. 275.—The Weston Method of Coiling.

The Elphinstone Machine.—In the dynamo-electric machines of Lord Elphinstone and C. W. Vincent, powerful magnetic fields are prepared by placing magnets both inside and outside, opposite to the coils. Figs. 276 and 277 represent this machine. The bearings S S carry the steel axis A X, at the middle of which six fan-shaped iron cores E are fastened; the shaft carries the driving-wheel *r* and commutator C. The wire ends of these six electro-magnets are carried through the steel axis. The turns are so arranged that north and south pole follow each other alternately round the circumference of a circle. Opposite to the shoes of these inner electro-magnets stand six shoes of the three outer electro-magnets M, of a V-shaped form. The currents in these are conducted in such a manner that opposite their poles stand the dissimilar poles

of the inner electro-magnets. Between these two circles of electro-magnetic poles the coils move and the currents are induced. The coils are fastened on a cylindrical drum of pasteboard, which is carried by the two bronze wheels R R. The coils themselves are thin and flat, so as to lie on the surface of the drum, and are arranged in the following manner: Upon six rectangular frames, the length of each of which is equal to the length of the pasteboard drum, and the breadth of which is one-sixth the circumference of the drum, insulated wires are wound in pairs. The six thin, flat, rectangular bobbins thus formed are

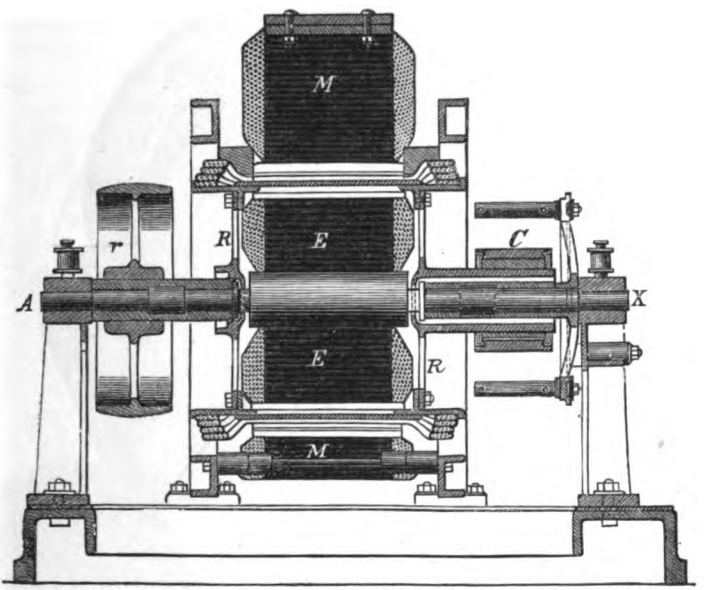


Fig. 276.—Section of the Elphinstone and Vincent Machine.

fastened to the drum, being slightly curved, so as to fit it closely, and then a second and a third layer of such bobbins is similarly laid down upon the first; the three sets of coils are not, however, super-imposed, but each layer overlaps the one underneath it by one-third of the breadth of a bobbin. Iron is not used in the preparation or fastening of the bobbins, but phosphor bronze. The coils consist of copper wire only, and have no iron cores. Each layer having six bobbins, and each bobbin having two double ends, $6 \times 3 \times 2 \times 2 = 72$ wire ends lead to the commutator, which consists of thirty-six pieces. The brushes are six in number, and are connected by copper cables to screws. By this arrangement the machine has three currents, which may be united in series or used separately, according to need. The wire ends of the electro-magnets lead also to screws, which admit of different modes of joining

up with each other, and also with the circuit of the machine. The E. M. F. of this machine can therefore be varied according to circumstances, and the magnetic field is intense, owing to the proximity of opposite magnetic poles inside and outside of the drum of thin flat coils.

Fig. 278 is intended to show the course of the current, and also the induction

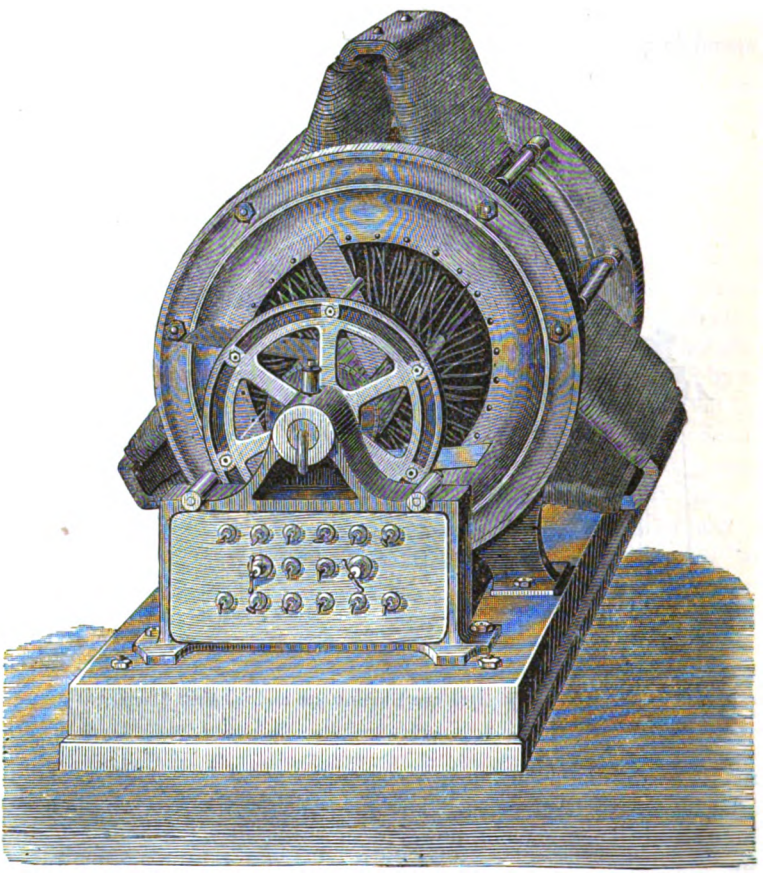


Fig. 277.—The Elphinstone and Vincent Machine.

phenomena in the Elphinstone machine, and represents a modification adopted in the most recently constructed machines. Instead of six, only two brushes are here employed. Instead of the double coils, single wires are shown in the figure, and the commutator has only eighteen portions here instead of thirty-six, so as to facilitate description. The inner magnets, which are opposite to the outer ones, are also omitted for the same reason. The curves I II and III represent the

different layers of bobbins. In each layer the end of the first coil is connected with the commencement of the one next to it; and from the point of connection wires are carried to a segment of the commutator. The connections between the segments of the commutator have been completed only for layer III, showing, therefore, only two brushes instead of six. Let us consider the induction effects of III: of the six coils, three are influenced at the same time by similar magnetic poles; therefore every three coils will have induced currents of the same direc-

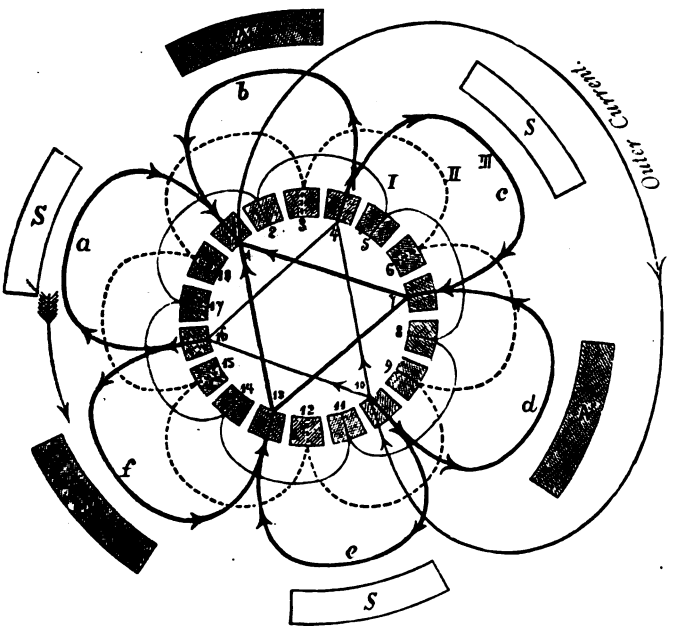


Fig. 278.—Diagram of the Elphinstone and Vincent Machine.

tion, viz. the coils *b d f* and *c e a*. In the coils opposite the north pole (the first three named) the current was assumed to flow anti-clockwise; it follows that the current in the coils *c e a* will flow clockwise. If we follow the direction of the current in the different coils, we find that currents of the same direction flow to the commutator segments 1 7 and 13, and currents of opposite direction to the segments 4 10 and 16. If each of these six points had a brush, the induced currents could be conducted into three different circuits. If, however, the segments 1 7 and 13 are connected with each other, and also the segments 4 10 and 16, by using only two brushes at 1 and 10 all the currents induced in the coil III may be conducted into one circuit. Following the directions of current in the different coils of this layer, and the connecting wires of the segments of the commutator, we find that at 1 currents of one direction, and at 10 currents of

another direction meet. If such points be connected with each other, a current of one direction will flow through the connection in the manner which we have already described when explaining the Gramme ring (page 249). For eight-tenths of a revolution of the armature, the coils of the different layers I II and III occupy the same position in relation to the magnet poles. If we use six brushes, at the moment when the coils of layer I are opposite the magnetic poles, segments 2 8 and 14 on one side, and segments 5 11 and 17 on the

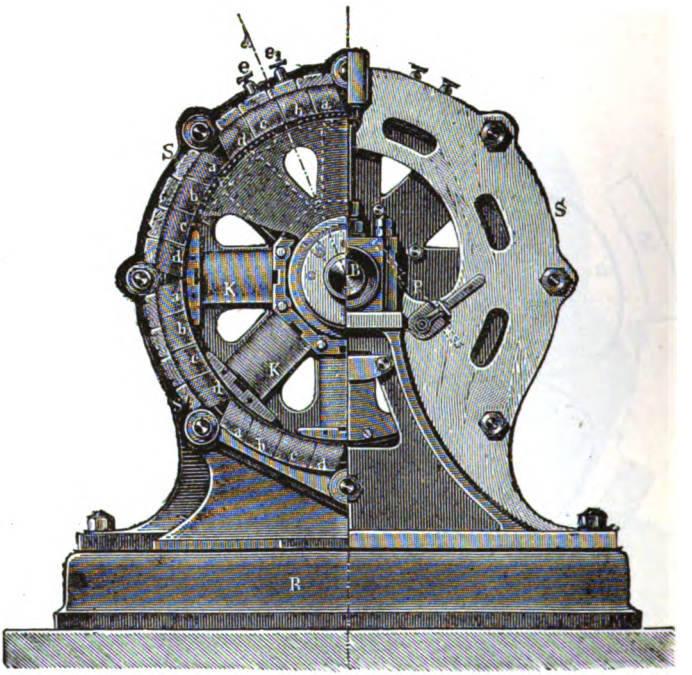


Fig. 279.—Gramme's Alternating Current Generator.

other, would come under the brushes. If only two brushes are used, segment 2, which then must be connected with segments 8 and 14, comes under one brush; while under the other brush comes the segment 11, from which wires must lead to 5 and 17. The same holds good for layer II. In this manner currents of one direction are obtained for the outer circuit.

ALTERNATING CURRENT MACHINES.

As we shall see later on, with the invention of Jablochkoff's electric candle a demand was made for a kind of machine in which the currents generated by the successive approach and recession of the bobbins should not be commuted. As these candles require alternating currents, several forms of machines producing

such currents have been constructed. Figs. 279 and 280 represent an alternating machine by Gramme. Upon the cast-iron base R the two cast-iron supports D, of almost circular form, are attached together with eight brass rods E and an iron stay U, which serve to give the whole greater solidity. To this frame the coils *a b c d* are fastened. The whole of the cylinder of coils is covered with a wooden frame S; F is a steel shaft which carries the eight electro-magnets K by means of the cast-iron sockets H and octagonal plates. Each of these electro-magnets has a shoe of soft iron rounded at the outer surface, and reaching beyond the electro-magnet, so that very little space is left between the shoes of two magnets. Two thin

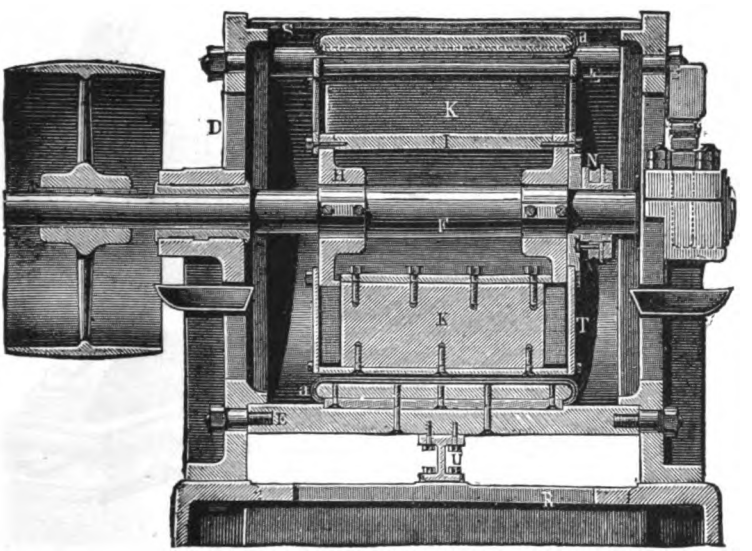


Fig. 280.—Section of Gramme's Alternating Current Generator.

discs T fastened to the different magnets protect them against the effect of centrifugal force. Upon the shaft at N are two insulated discs; and upon these the brushes P slide. They serve the purpose of conducting a current to the electro-magnets, which is usually supplied by a small auxiliary Gramme machine. The electro-magnets are coiled alternately to the right and to the left, and all are included in the electrical circuit. The effect of a current flowing through all the coils will be such that when a magnet has its south pole facing the coils *a b c d*, the neighbouring magnets to the right and left will turn their north poles outwards, *i.e.* the electro-magnets following each other in a circle will have alternately south and north polarity. The eight groups (each group consisting of the wires of four coils) are not connected to one large coil, as in the Gramme ring, but the wires of each coil lead to a binding screw $e\ e_1$, fastened upon the wooden cover S. By this arrangement the machine may give thirty-two separate

currents. The way in which the machine works is now easily seen: As the armature has eight groups of coils, and the shaft eight electro-magnets, the effects of induction will be the same in each of the different groups; for instance, when a magnet comes just opposite one group of coils, on account of the equality of the number of groups and number of magnets, every other group of coils will also have a magnet opposite it. The strength, therefore, of the induced currents will be

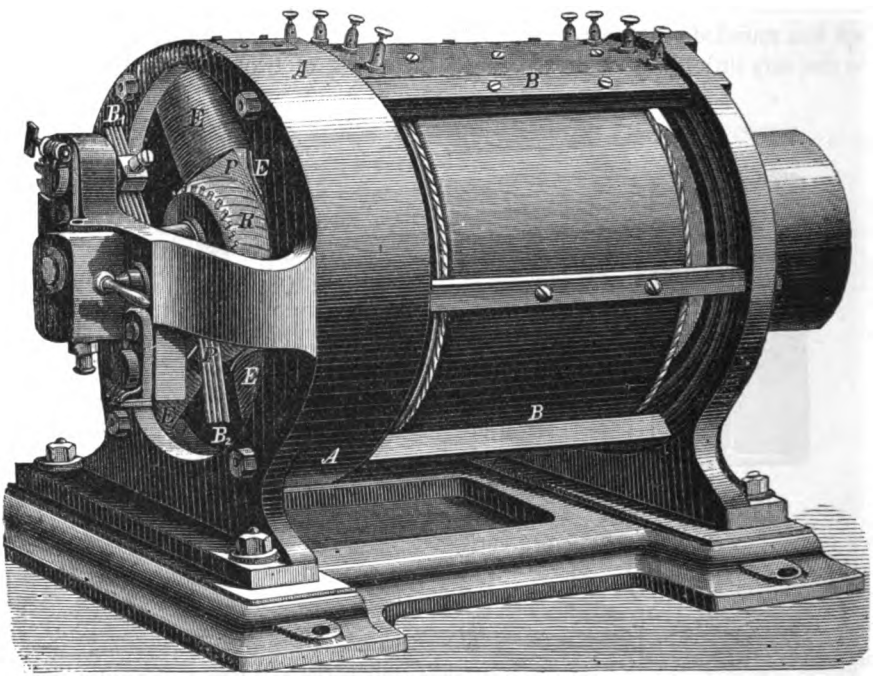


Fig. 281.—Auto-Excitatrice.

the same at all times in all the groups of coils, but their direction will change as different poles come opposite the different groups. While the groups 1 3 5 and 7 have currents in one direction, groups 2 4 6 and 8 will have currents in the opposite direction. If every separate coil be closed, thirty-two circuits will be obtained, and in each of them alternating currents will be produced. To obtain four circuits we have but to connect the 1st, 3rd, 5th, and 7th coils *a* for one of the poles, and the 2nd, 4th, 6th, and 8th coils *a* for the second pole; also 1st, 3rd, 5th, and 7th coils *b* for one pole of the second circuit, and 2nd, 4th, 6th, and 8th coils *b* for the other pole, the coils *c* and *d* being connected in the same manner for the desired four circuits. In this manner four separate circuits are obtained, in each of which alternating currents of the same strength are produced. The machine shown in Figs. 279 and 280 feeds sixteen Jablochkoff's

candles, each of 1,000-candle power, requiring sixteen h.p. It costs, including an auxiliary machine, 10,000 francs = £400; its length is 0·89 metre, breadth 0·76, height 0·78; the maximum velocity is 600 revolutions per minute, the weight 650 kilogrammes. As the machine supplying the current for the electro-magnets is as a rule separated from the principal machine, the slightest fluctuation of current in the former produced considerable disturbances in the latter, and consequently unsteady lights. Gramme has dispensed with the independent generator by uniting the two machines, and to this new alternating current machine he gave the name Auto-excitatrice. Fig. 281 represents the combina-

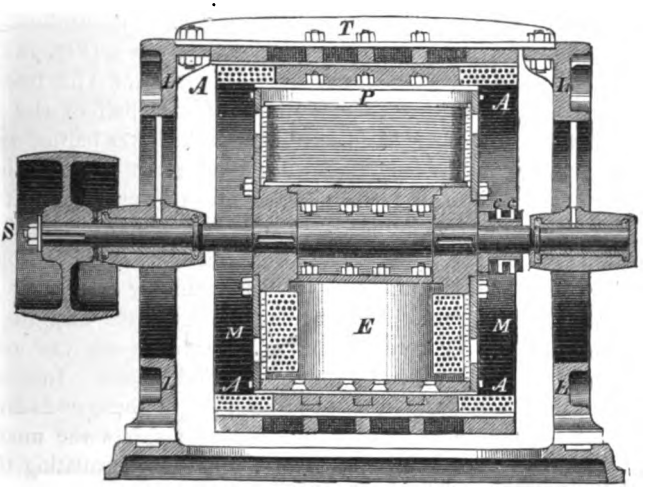


Fig. 282.—Zipernowsky's Machine.

tion of a Gramme machine A (for currents of one direction) with the alternating current machine B. The arrangement of the inducing electro-magnets is slightly different here from that of the ordinary ring machine. From the inner side of the cylindrical supports A A the electro-magnets E spread in radial directions. At the vertices the two shoes or pole-pieces P P are fastened so as to connect the electro-magnets two and two. The wire of the electro-magnets is so coiled that every two ends, connected by a shoe, have similar polarities. Within the cylindrical space formed by the shoes, a Gramme ring R of the ordinary construction rotates, *i.e.* it moves between two diametrically opposite magnetic poles, and experiences therefore the same inductive influence. The ring is fastened to the axis which carries the inducing electro-magnets of the alternating current machine B. The currents induced in the ring R are conducted by the brushes B_1 B_2 to the electro-magnets of the alternating machine E. For the purpose of regulating the currents of both machines, the brushes of the generating machine are not directly connected with the wire coils of the electro-magnets, but are

arranged in such a manner as to allow of the insertion or removal of resistance coils. The manner of wrapping the coils differs also in the later constructions. A double wire is used instead of a single wire, to allow a modification of current suitable for small or large lights.

The auto-excitatrice not only gives better results than the old machine, but also costs less. A machine weighing 470 kilogrammes furnishes currents for twenty-four Jablochkoff candles of 200 to 300 candles each, or sixteen lights of double that power. A machine for feeding twelve of the smaller lamps weighs 280 kilogrammes.

The machine by Zipernowsky (of the firm Ganz and Co., Budapesth) is similar in construction to the Gramme alternating current machine. The inducing magnets, however, have flat prismatical iron cores E (Fig. 282). Six of them are fixed in the form of a circle upon the shaft. The free ends are furnished with shoes or pole-pieces P. In the upper half of the figure the wire coils are drawn on the plane of an iron core, in the lower half of the figure a further section is made, and by leaving out the first layer of wires the iron core E is shown. The metal discs M M serve the purposes of ventilation, as well as to prevent the generation of useless induced currents (Foucault's or "eddy" currents). The construction and arrangement of the armature coils A A differ from those of the Gramme model. Gramme arranges the latter radially as regards the drum surrounding the electro-magnets. In the machine by Ganz and Co. they are concentrically arranged. The cores of the induction coils are cast or wrought-iron sectors, and are lined with zigzag-shaped wood pieces. Instead of wires stamped copper sheets are used, slit open at both ends; these ends are soldered alternately, so as to form a closed spiral. Fig. 283 shows the mode of connection of two of them. For insulating the several turns, asbestos or paper is used. The coils are arranged in the form of a drum, and they are joined up either parallel or in series. Both ways of joining up allow of the currents being thrown into one current or being grouped in several. The drum is covered with layers of thick paper, which are held together by wooden rings (Fig. 282). In the grooves formed by the wooden rings on the surface of the drum well-annealed iron wires are wound, or the space is filled by thin iron rings; this arrangement not only adds to the solidity of the drum, but also increases the induction effects of the coils. The fastening of the drum to the bearings L is brought about by the transverse rods T, to which also the armature coils are screwed.

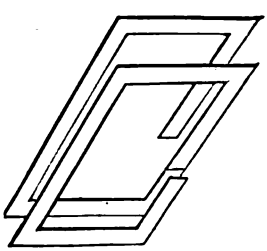


Fig. 283.—Spiral Armature.

Siemens' Alternating Current Machine.—Siemens obtained alternating currents by using flat coils rotating in powerful magnetic fields. The alternating current machine by Siemens and Halske is shown in Fig. 284, together with its small generating machine. To the ground plate of the machine two cast-iron supports held together by a cross-bar at the top, are

screwed; each support carries twelve electro-magnets, the coils of which are so arranged that whenever a current flows through the coils each possesses the opposite polarity to its neighbouring as well as to the opposite magnet. Between

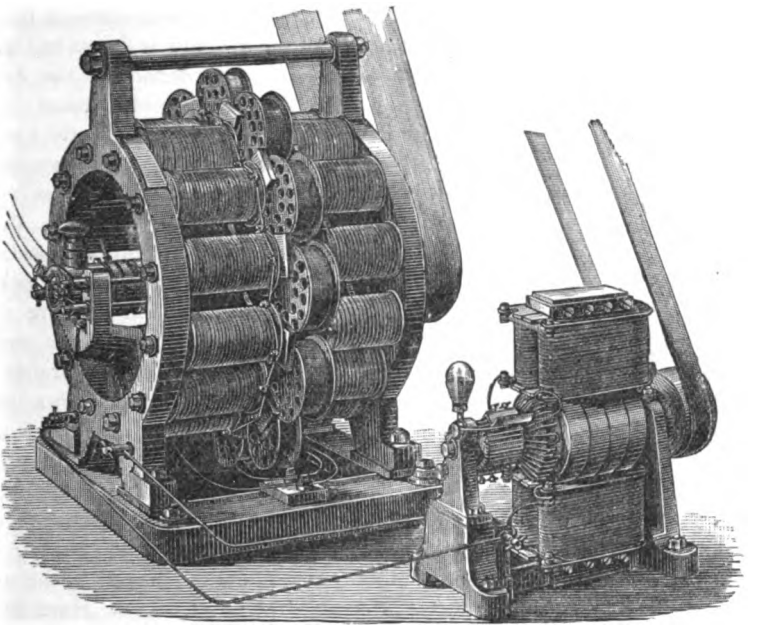


Fig. 284.—Siemens' Alternating Current Machine.

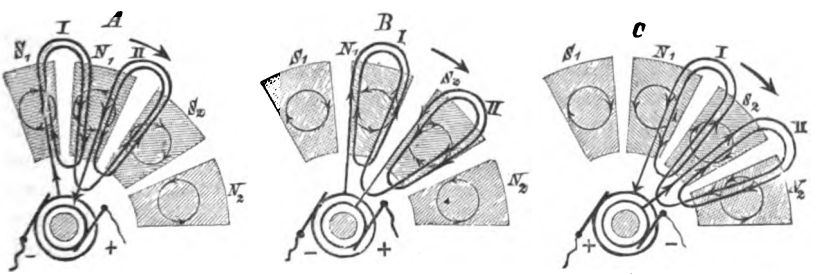


Fig. 285.—Diagram of Siemens' Alternating Current Machine.

the poles of these electro-magnets rotates a disc, which carries the bobbins, the cores of which are made of wood. When the disc rotates, every coil has to pass all the magnetic poles in turn, *i.e.* each coil is exposed alternately to the effects of the inductions of differently polarised magnets. The currents induced in a coil will therefore change their direction as the coil passes from

one to the next magnetic pole. The machine possesses as many coils as there are pairs of electro-magnets, every two opposite magnets constituting a pair; therefore, the change of current takes place in all the coils at one and the same time. The currents induced in the coils are conducted to a series of rings fastened to the axis of the machine. The electro-magnets receive their currents from the small auxiliary machine. The mode of action of the machine is shown in Fig. 285, A B C; S and N indicate the magnetic poles (with the direction of the Ampère currents indicated). The outer arrow indicates the direction of rotation. In the position A the coil I moves away from the pole S_1, and consequently a current will be induced that flows clockwise; at the same time coil I approaches N_1, and a current clockwise will here too be induced. The poles N_1 and S_1 mutually assist each other. Coil II moves away from N_1 and approaches S_2, and has therefore currents anti-clockwise. If now the coils I and II were simply connected with each other, the currents induced in the coils would neutralise each other. This, however, as shown in the figure, is prevented by having I coiled towards the right, and II towards the left. By this arrangement currents of opposite directions are obtained, which can easily be seen by following the arrows. The total currents are conducted by the springs + − into the outer circuit. Here we have taken into account only one row of magnetic poles; but in reality the coils I and II move between two rows of magnets with their opposite poles facing each other, thus the south pole S_1 has a north pole opposite it; and the north pole N_1 has a south pole S_1 opposite, and so on. It may be asked here whether the induction phenomena are the same as in the machines last described, and the answer will be afforded by Fig. 286, which represents a couple of magnetic poles, and the coil I in the same position as in Fig. 285 A. The Ampère currents move at the south pole clockwise, at the north pole anti-clockwise. As the two magnets face each other the Ampère currents on their fronts flow parallel to each other, as shown by the arrows in the figure. Coil I moves away from this double pole, and must therefore have a current induced which has the same direction as the Ampère currents. If we compare the direction of current for coil I, in Fig. 286, with the direction in Fig. 285 A, we find that the direction in both is the same. It follows that the action of the magnetic pole N_1 is exactly like that of the opposite pole S_1. As the magnets are all alike, the same will become true for all the couples. The coils I and II (Fig. 285 A) having left the poles S_1 and N_1, next approach the position seen in Fig. 285 B. As the coil I moves away from S_1, it approaches S_2, and both S_1 and S_2 will induce currents in the coil, but the recession causes

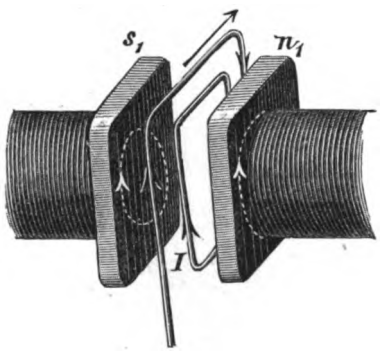


Fig. 286.—Coil and Magnetic Poles.

a current in one direction here clockwise, and the approach causes a current in the opposite direction, viz. anti-clockwise. If poles S_1 and S_2 are of equal strength, their induced currents in coil I will neutralise each other. But we have also to consider the effect which N_1 has upon the coil I. Let us assume the magnetism of this pole to be concentrated at its centre. When the right-hand side of the coil approaches, the induced currents will flow from below upwards, and when the left side moves away its currents too will flow from below upwards. The currents then induced by N_1 in the coil I are equal and opposite to each other, and consequently neutralise each other. The mean result of the inducing effects of poles S_1 N_1 and S_2 upon coil I in this position is therefore equal to 0; *i.e.* the coil at this instant is currentless. Coil II (Fig. 285 B) is also currentless. But as the rotation continues the coils will reach the position 285 C. If we do not take into consideration the polarity of the magnets, the coils at C have the same position as at A; but there is this difference as regards the poles: in the position C coil I moves away from a north pole, and coil II from a south pole, whilst in position A the reverse took place. A current will flow through the coils at C also, but the direction of this total current will have the opposite direction to the total current induced at A. We thus see that as the coil continues to rotate it will now reach a position like B, then one like A, then again one like B, and so on. There is thus a continued oscillation in the direction of the current in the outer circuit, with an interval between each change. What holds good for the two coils under consideration must hold good for the rest of the coils in the machine, assuming that there are as many coils as there are magnet couples. By this arrangement, whenever the coil I is opposite a north pole all the coils with uneven numbers will be opposite north poles, and all the coils with even numbers will be opposite south poles. If, therefore, the even coils are connected with one conducting ring, and the odd coils with another, springs sliding upon these will collect all the current for the outer circuit. Owing to the equality of number of magnets and coils, the direction of current in all the coils will change at the same time; and in the outer circuit currents which continually change their direction will be obtained, interrupted by the interval that takes place during the change of current. This interval, on account of the rapid motion of the coils, is of such short duration that it is not at all noticed in the outer circuit.

Siemens and Halske also construct machines for continuous currents, which are very similar to this alternating current machine. The chief difference between the two machines is that the continuous current machine has not as many coils as there are magnetic fields; for instance, if the machine has ten magnetic fields, the rotating disc will have only eight coils. The electro-magnets are arranged as in the alternating current machine, *i.e.* each pole has opposite polarity to the neighbouring and opposite poles. How then are steady currents produced in the outer circuit? The ends of all the coils are connected with each other in such a manner that they form a continued circuit. One coil is right-handed, the next to it left-handed. If, therefore,

two adjacent coils approach two consecutive magnetic poles (opposite in kind to each other), currents of different directions would be induced; the turns in the coil, however, being opposite to each other, the currents will have the same direction, and each will aid the other. The current induced in these coils does not maintain this direction as the rotation continues, because coil I passes alternately a north pole and south pole, while coil II in a similar manner passes alternately a south pole and a north pole. It follows that the direction of the induced currents must alternate. The machine would therefore generate alternating currents if it were not provided with a commutator. This commutator is carried by the shaft, and is of the same shape as that used in the Gramme machine. It consists of a collecting cylinder, composed of forty pieces and divided into five groups of eight each (Fig. 287), and insulated metal rings that are also fixed one behind the other on the shaft of the generator. The coils which surround the cores of the magnets form a continuous circuit, and the flat pole-pieces are represented in Figs. 287 and 288, the black rectangle standing for N polarity, and white standing for S polarity.

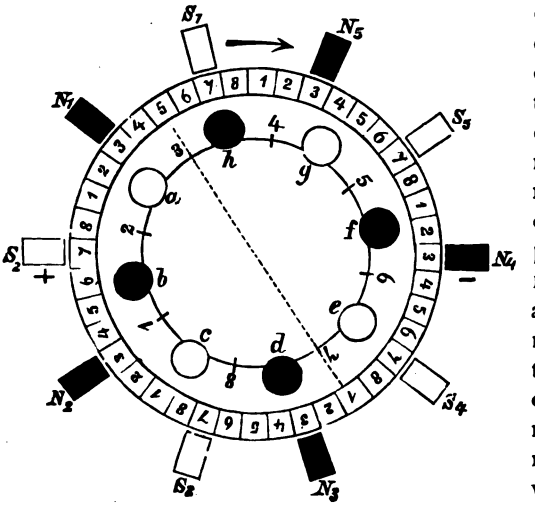


Fig. 287.—Commutator of Siemens and Halske's Continuous Current Machine.

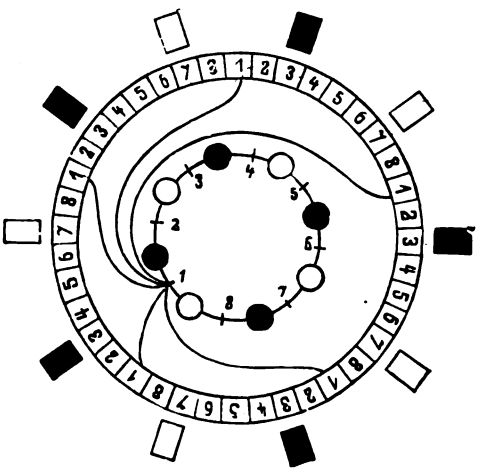


Fig. 288.—Commutator of Siemens and Halske's Continuous Current Machine.

The armature coils are wound on wooden cores, as in the alternating current generator. As the number of the bobbins in the armature is two less than the number of the magnets attached to the iron standards, the angular distance

between the bobbins is greater than the angular distance between the magnets. The bobbins, therefore, do not all arrive simultaneously opposite the magnetic poles. This is, in fact, only the case with two of them, the others being farther from the poles they are about to approach. The coils of the armature form a single continuous circuit, but the coiling changes in direction from bobbin to bobbin, the right-handed coiling being represented in the figure by white circles, and the left-handed coiling by black circles.

All the parts of the collector numbered 1 are connected by wires with the ring 1 on the shaft, and this ring again is connected with the point of junction No. 1 of the two armature bobbins *c* and *b* (*see* the letters in Fig. 287, and lines for the connecting wires in Fig. 288). In like manner every connecting wire of two consecutive coils of the armature is similarly connected with five portions of the collecting cylinder by means of a metal ring. The point of connection 2 of the two next coils will then be connected with all the segments indicated by the figure 2, and so on. We see from the diagram that between every two succeeding segments of one group seven segments of other groups are situated. In Fig. 287 the black rectangles and circles for magnetic poles and coils are lettered. Segments and bobbins rotate in the direction of the arrow (*i.e.* clockwise). A current of one direction will be induced when bobbins of one colour approach the like-coloured magnetic pole. A current will be induced in the opposite direction when bobbins of different colours approach the magnet. Let us assume that the approach of bobbins and magnets of the same colour, both black or both white, brings about a current in the outer circuit which flows clockwise, and that the approach of coils of a different colour brings about a current which flows anti-clockwise. Brushes which slide upon the segments of the collecting cylinder at + and − conduct the induced currents into the outer circuit. The maximum strength of current does not occur at the same instant in all the bobbins, but at successive intervals. In the positions indicated the coils *a* and *e* will experience the maximum of the inductive influence. When the coil *a* approaches the black magnetic field N_1, the current induced will have the direction anti-clockwise. The white coil *e* approaches the white south pole s_4; hence the current induced will flow clockwise. We know that the wire terminal 3 of coil *a* is connected with all the segments having the number 3; one of these now will be connected with the brush, so that the current induced in coil *a* will be conducted into the outer circuit. The wire terminal 7 of coil *e* is connected in the same manner with all the segments of the collector marked 7, one of these being in contact with brush *f*; the current then induced in coil *e* clockwise will be conducted also to the outer circuit. The directions of currents with and against the clock here, where one coil approaches a north pole and the other a south pole, means the setting in motion of positive and negative electricity. But the motion of the two electricities in opposition to each other in one and the same conductor constitutes the electric current. As the rotation continues the coils which will next experience the greatest amount of induction will be the coils *b* and *f*. The black coil *b* approaches the

white south pole S_2; the induced current is therefore anti-clockwise. Now a segment of the collector having the number 2 comes under the – brush; again, then, negative electricity from the brush is conducted into the outer circuit. At the same time the black coil *f* reaches the black field N_4, and the induced current here will flow clockwise. Segment 6 is under the + brush; positive electricity then flows from this segment into the outer circuit. The rotation may be continued for any length of time, the same result being thereby continued—*i.e.*, positive electricity will be conducted by the + brush into the outer circuit, and negative electricity by the – brush. The machine, therefore, furnishes continuous currents, on account of the arrangement of its commutator.

The above is the explanation of what occurs by means of Ampère's rule; the equivalent explanation by means of Maxwell's rule is afforded by the dotted line 3 7, which divides the figure into two halves. In the one half differently coloured coils approach the magnetic fields, whilst in the second half coils and magnets of the same colour only approach each other. The number of lines of force embraced by each bobbin is increased positively for one side, and negatively for the other. The phenomena observed here are, therefore, analogous to the phenomena in the Gramme ring; here the magnetic fields are fixed, whilst in Gramme's ring the current branches are fixed. From the position in which the maximum number of positive lines is embraced by a coil to the position in which the same number of negative lines is embraced is half a revolution; and, the decrease of positive lines and increase of negative lines being equivalent, the current has the same direction for this half-revolution. As described on p. 248, currents of opposite directions are induced in the two halves, and where these currents meet on one side there is a maximum potential, and where the opposite currents meet on the other there is a minimum potential, and from these points the currents can be conducted away and be united.

The machine we have here described has ten electro-magnets and eight armature bobbins. This, however, may be varied, provided the number of coils is not the same as the electros. We may have, for instance, either n or $2n$ bobbins and $n + 2$ magneic fields, or $n + 2$ bobbins and n magnetic fields. With $2n$ bobbins and $n + 2$ magnetic fields, there is a special advantage; there is a more uniform pull of the parts; there is less sparking at the collector; and the action of the machine is altogether smoother.

This construction of continuous current generators has certain advantages over the cylinder and ring machines. In the former the electro-magnets are directly influenced by a continuous current, which flows through its coils; in the latter machines one pole of each magnetic field is influenced by induction. The coiling of the wire in the former machine is very simple, and as changes of polarities are avoided, the machine is not heated so much.

The Ferranti-Thomson Generator.—Fig. 289 represents the alternating current generator by Ferranti-Thomson, which is the result of the labours of Sir William Thomson, Ziani de Ferranti, and Alfred Thomson. Fig. 290 shows the armature of this machine. The shaft carries two blocks insulated

from each other, and from the shaft between these blocks there is a brass ring, also insulated, to which at regular intervals the copper bands of the armature are attached. The eight coils of the armature consist of copper bands of 31 mil-

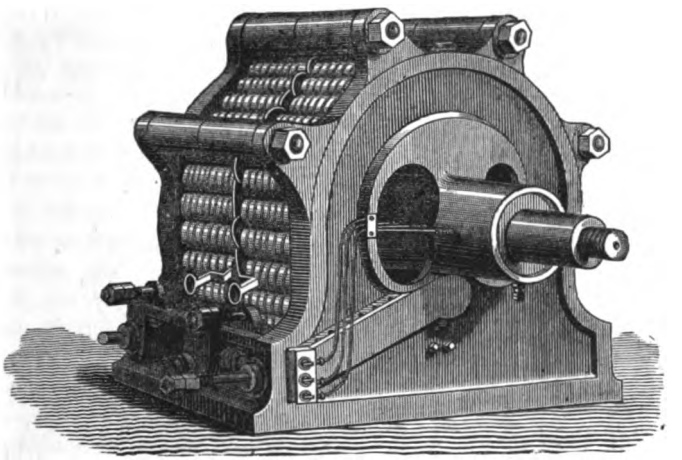


Fig. 289.—The Ferranti-Thomson Machine.

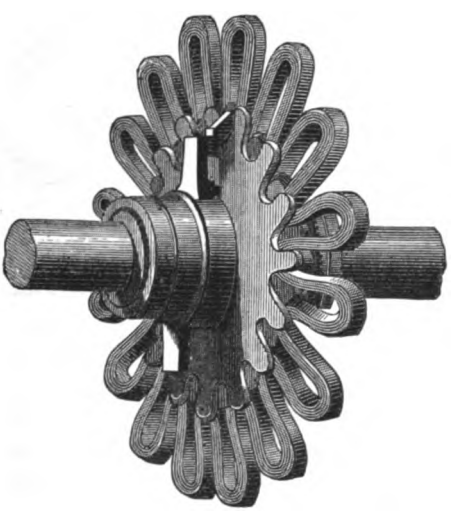


Fig. 290 —The Ferranti Armature.

limetres breadth and 1·75 millimetres thickness, all having electrically the same value. The bands are of the same length, and have the same shape. The construction of the armature is best seen in Fig. 291. To prevent complication,

only eight coils of four bands each are arranged. The first copper band I begins in the curves *a* and *b*, and is continued over *c* and *d*, but so that in the next coil it comes *over* the second copper band II, which commences at curve *c*, and for this curve and the curve *d* forms the lowest layer. Copper bands I and II are continued together until they reach *e*; here the copper band III commences, and forms the lowest layer for curves *e* and *f*. The three copper bands are now continued till they reach curve *g*; here the fourth and last copper band

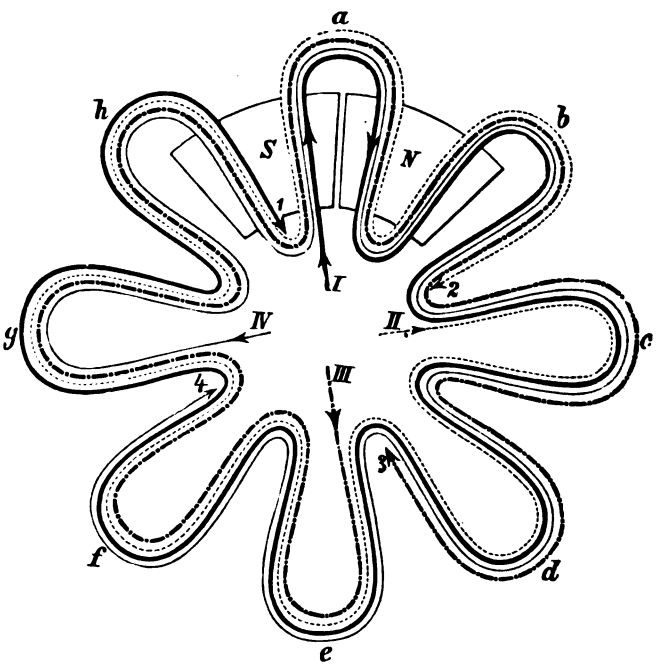


Fig. 291.—Diagram of the Ferranti Armature.

commences. The curves *g* and *h* now consist of all the four bands. The copper band I ends at curve *h*, but the three other bands continue their way; at curve *b* ends the second band at 2, bands III and IV end at 3 and 4. Each copper band is conducted through all the curves in such a manner that it forms the first layer in two curves, the second layer in the two next curves, then the third layer, and finally the fourth layer, where it ends above its starting point. The same length and a similar course are obtained in this manner for all the bands. The several copper bands I_1 and II_2, &c., are insulated from each other. The armature has a diameter of 0·9 metre, and makes 1,000 revolutions per minute. Upon the shaft at both sides of the armature two collecting rings are fixed. One of these is connected with a brass ring, the

other is connected with the ends 1 2 3 and 4 of the copper coils. From the brass ring, at the points I II III and IV, the copper bands start. To connect the different parts with each other, solid pieces are used instead of wires. The currents induced in the copper bands are not conducted by brushes into the outer circuit, but here also, instead of brushes, metal pieces are used, being pressed by springs against the rings. When we compare Fig. 291 with Fig. 285, we find that the principle is practically the same. For coil *a* (Fig. 291) the surrounding magnets S N are shown, and the directions of the current induced in the copper are indicated; band I_1 of curve *a* is indicated by the arrows. The remaining copper bands II_2 III_3 and IV_4 of curve *a* will have their currents in the same direction. Owing to the arrangement of the copper bands, and in consequence of the alternating arrangement of the surrounding magnets, at every moment during rotation currents will be induced in all the curves passing in the same direction through the armature. Therefore one of the collecting rings connected with the ends I II III and IV will receive from all the coils electricity of one kind, and the other collecting ring connected with 1 2 3 4 will receive electricity of the other kind. If the motion continue, a currentless interval will occur, and then a current of opposite direction, and so on. Ferranti arranges the turns of his armature in continuous order, whilst Siemens divides them into groups. In fact, the Ferranti mode of winding the armature had been tried by Siemens and Halske, and the experiment led to the construction adopted in the alternating current machine, as the plan of dividing the bobbins into groups seemed more advantageous.

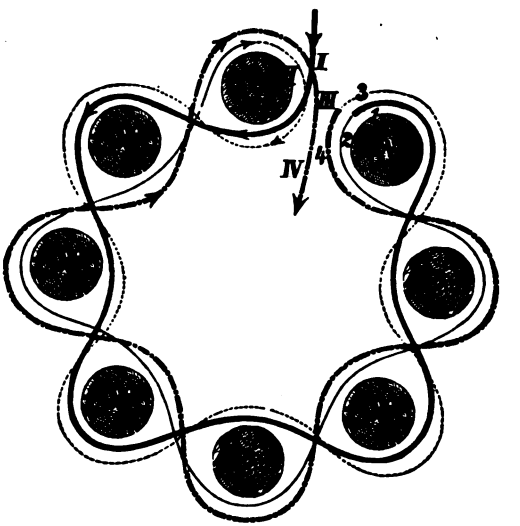


Fig. 292.—Diagram of Ferranti's Electro-Magnet.

Facing the armature on each side thirty-two magnets are arranged. The iron cores are cast in one piece with a half-frame of the machine. The two halves face each other, and are held together by six horizontal bolts. The coils of the electro-magnets are copper bars having a section from 18 to 22 millimetres. Fig. 292 shows the manner of coiling for eight magnets. The magnets, which practically stand close together, are here separated from each other, so as to show the different curves more distinctly. In commencing the coiling, copper bar 1 is wound round the first iron core, and round the second core in the opposite direction, and so on-until it comes to the last core, where it ends at 1. Upon

this the second layer is coiled (II), ending at 2; then comes the third layer (III), indicated by the five dotted lines in the figure, ending at 3; and the last layer (IV), ending at 4. The end of the first layer 1 is joined with the end of the second layer 2, and so on through the series, so that all the layers together form one continuous circuit, commencing at I and ending at IV. Practically the layers would be close together, of course. If we follow the curves representing the copper bars, we find that the successive iron cores must be surrounded by currents with alternate directions, and therefore the north and south polarity must constantly change The electro-magnets themselves appear arranged in series, as the current has to flow through all the copper bars, of which there are nine. In order to insulate the different layers from each other, at every bend of the bars insulating pins are placed. The current is introduced into the coils of the electros by means of the ring seen on the left hand of Fig. 289, when the current will flow through one series of magnets, then through the second series of magnets, and then leave the field coils by means of the second ring of the machine. By 1,000 revolutions per minute a current of 2,000 amperes, with an E. M. F. of 200 volts, is produced. The machine is intended to feed incandescent lamps, therefore its resistance is made as little as possible.

In event of damage, this machine is not so easily repaired as the Siemens machine. The current for the electro-magnets is furnished by a continuous current machine, in which the magnets have the same construction as in the machine just now described. The copper bars have a cross section of from 37 to 85 millimetres; the armature consists of five curves, each curve having four copper bands, the breadth of which is 37 millimetres. The bands are joined parallel (*i.e.* with a quantity arrangement) and are connected with a peculiarly constructed commutator. The armature makes from 300 to 400 revolutions per minute, and furnishes a current of 800 amperes, with an E. M. F. of 10 volts. A published report respecting a machine exhibited in London in 1883 at the Aquarium is as follows: The machine makes 1,900 revolutions per minute, and is driven by two leather belts, which run with a velocity of 5,000 feet per minute. In spite of the great speed of the machine, the 320 Swan lamps which the machine is supposed to feed are only indifferently supplied. The light of the lamps appears redder than that of the gas lamps. The amount of horse-power bears no definite or constant relation to the effects produced. It is stated further that the waste and heat produced by the machine are more considerable than in most machines. It seems that with this machine the practical velocity has been over-reached, so that, notwithstanding the theoretically correct construction, no practical success has been attained.

The Gérard Generator.—In the continuous current machine by Gérard, alternating currents are induced in the bobbins of the armature as they rotate past the magnets; the alternating currents, however, are converted into a continuous current in the outer circuit by means of a commutator. The frame of this machine is an iron cylinder (Fig. 293), at the ends of which fork-shaped pieces are fixed to support the cast bronze bearings of the shaft. The frame

carries internally the four field magnets N, S, N^1, S^1, which are furnished with hollowed soles or pole-pieces. Attached to the steel shaft are also four iron cores, in the form of a cross, round which the coils are wound; two of these are visible in the figure (Fig. 293), and are indicated by the Roman numbers I and IV.

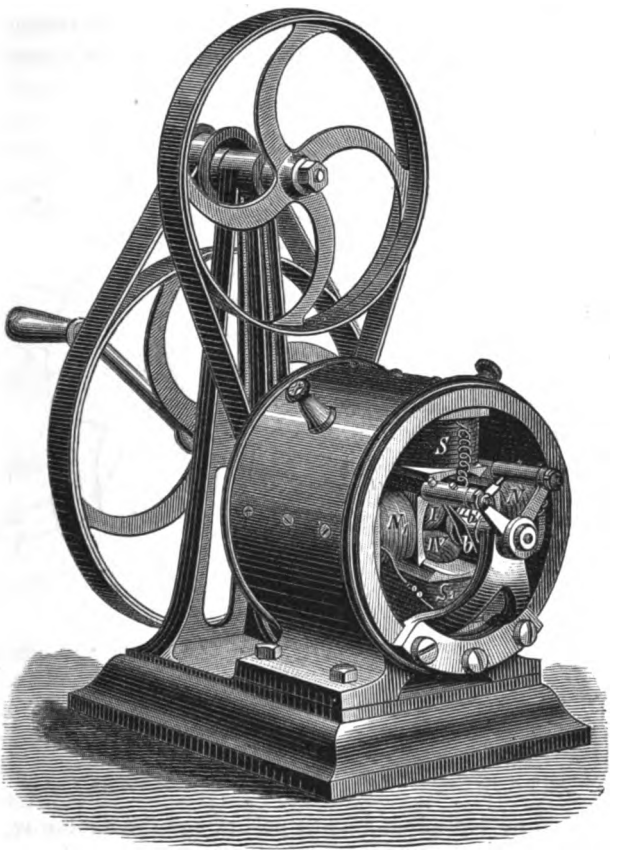


Fig. 293.—The Gérard Machine.

The armature, fixed to the shaft, thus consists of four coils, connected in series. The commencement of the first and the end of the last lead to one of the insulated portions of the commutator, of which there are two. The manner in which these are cut out is shown in Fig. 294 A, separately.

This figure is a diagram to show the course of the current in a Gérard machine. At N N_1 S S_1 there are two loops of the wire marked by continuous lines to indicate the electro-magnets, and at I II III IV there are loops marked by dotted lines to represent the four bobbins of the armature. 1 2 3 and 4

represent the horizontal sections of the commutator, and b b_1 the brushes, sliding upon them. The arrows show the direction of the current, which at S, as south pole, must be in the direction of the hands of a clock facing us, or, as we will call it, clockwise; at N counter-clockwise, at S_1 clockwise, and at N_1 again counter-clockwise.

In Fig. 294 A that particular condition of rotation is represented where the bobbin I is just opposite the north pole N_1, the bobbin II opposite the south

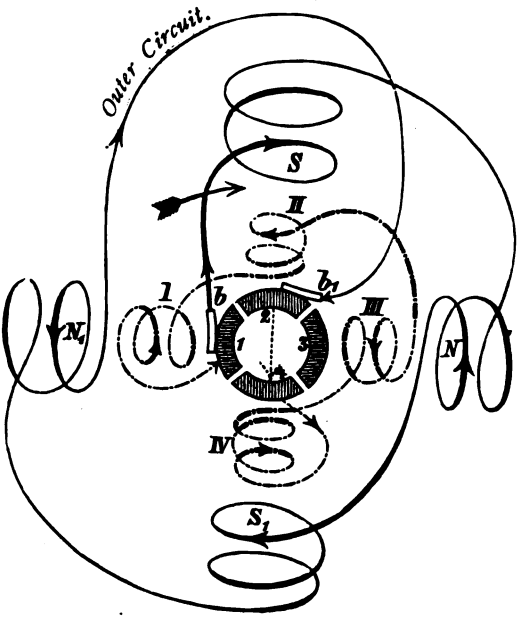


Fig. 294 A.—Diagram of Gérard Machine.

pole S, the bobbin III opposite the north pole N, and the bobbin IV opposite the south pole S_1. Hence, the direction of the currents induced in the bobbins at the corresponding magnetic poles are opposite to those of the magnet currents; that is to say, they have the directions marked by the arrows in the bobbins I to IV. Let us now follow the currents through the whole interior and exterior circuit of the machine, beginning at the segment I of the commutator. The current induced in the armature passes from the "commutator segment" I, at which one end of the bobbin I is fixed, through the brush b into the windings of the electro-magnet S, thence into those of the magnet N, round which it flows in a direction opposite to the original direction; after this it passes into the windings of the magnet S_1, in which the current resumes its original direction; and finally the current moves through the windings of the fourth electro-magnet N_1, in the

same direction as that in which it passed round N. After this the current goes through the exterior circuit, for lighting or other work, and returns through the brush b_1 into the commutator.

The "commutator segment" 2, upon which the brush b_1 slides, is connected with the segment 4; thus the circuit, after passing through the electro-magnets and exterior circuit, is brought into the circuit of the armature. In the armature, the currents pass from the segment 4 into the bobbin IV, then pass in succession through the bobbins III II and I, the wire ends of which, as has been already said, are attached to the "commutator segment" I.

As the armature moves in the direction of the barbed arrow, the positions Fig. 294 B, C, and D will be reached. In position B, coil I has arrived at S, coil II at N, coil III at S_1, and coil IV at N_1. In the diagram of this and the other

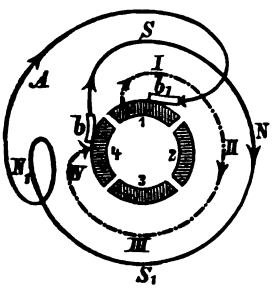


Fig. 294 B.

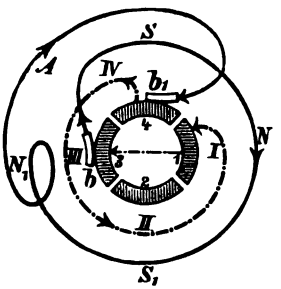


Fig. 294 C.

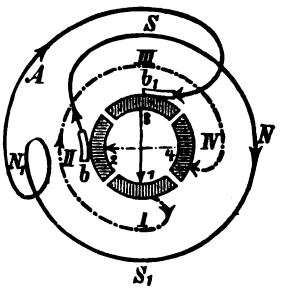


Fig. 294 D.

positions all the turns of the armature and magnets are left out, and their positions indicated by the respective figures or letters.

In the position Fig. 294 A, the currents flow in the circuit of the electro-magnets, in the direction from S over N S_1 and N_1, *i.e.* clockwise, as in the outer circuit. In the circuit of the armature the currents flow from coil IV over III and II to I, *i.e.* anti-clockwise. In the position Fig. 294 B, the coil I has arrived at S: the four coils have now reached the positions that are opposite to those in A, the currents therefore induced in position B will have the opposite direction to the currents induced in A. But owing to the action of the commutator, the currents will have the same direction as before in the circuit of the magnets and the outer circuit A. When coil I arrives at S, and coil IV at N_1, the commutator segment I comes under the brush b_1, and segment 4 under the brush b, and the currents will flow as follows: The currents induced in the armature flow from coil IV into the segment 4, through the contact spring into the circuit of the magnets, flowing from S over N and S_1 to N_1 into the outer circuit A, through brush b_1, and back again to the commutator. In position C coil I has arrived at N, II at S_1, III at N, and IV at S. The coils I and III, as in position A, have again a north pole opposite to them, and the coils II and IV a south pole.

The direction of current in the armature circuit must be the same as in position A, *i.e.* anti-clockwise. Coil I now stands opposite that north pole which was opposite coil III in A. The change of II with IV can make no difference, as both the north poles and south poles have the same relative position. But the position of the commutator has changed, and the flow of current in the different circuits will be as follows: The currents induced in the armature reach segment 1, which is connected with segment 3, from there through the spring *b* into the circuit of the magnets, S N S_1 and N_1; then through the outer circuit A, then back again to the commutator, through the contact spring b_1. We see, then, that the direction here for the field magnet's circuit and the outer circuit is the same as in positions A and B. When arrived at position D, the coil I will stand opposite S_1, II, N_1, III, S, and IV, N. The armature here has the opposite position to that which it had at B. The coils I and II are again opposite south poles, the coils II and IV opposite north poles. The direction of current in the armature circuit will be the same as in B, *i.e.* clockwise. Segment 2 comes now under brush *b*, and segment 3 under brush b_1. The flow of current in the circuits will be as follows: Currents induced in the armature flow through segment 4, then in succession to 2, to *b*, into the circuit of the electros S N S_1 N_1, then into the outer circuit, A, and back to the commutator, through brush b_1; connection with the armature coils is brought about by segment 3, upon which brush b_1 slides; 3 and 1 are connected with each other.

All currents induced in the coils of the armature flow through the exterior circuit in one direction, although the several coils pass alternately through a north and south magnetic field, changing the field every fourth of a revolution.

The smaller sizes have the field magnets connected in series with the bobbins of the armature; the larger ones with field magnets connected as a shunt to the armature.

One of these machines, weighing forty-five lbs., and costing £10, produces a current of ten amperes, and an E. M. F. of forty volts, when worked by three-quarters of a horse-power; while one weighing eight times as much, and costing £37, produces twenty amperes at one hundred volts, and lights thirty incandescent lamps of twenty-candle power each, from a horse-power of three and a half.

Gérard's continuous current machine is constructed in different sizes, for different purposes. The smallest (No. 00) gives a current equal to that of two Bunsen's cells. The next size (No. 0), shown in Fig. 293, furnishes a current equal to ten Bunsen's cells. Size No. 2 is intended to supply with current five arc-lamps, each equal to 500 or 600 standard candles.

Gerard's Alternating Current Generator.—The alternating current machine, by Gérard (or Société anonyme d'Électricité), is shown in Fig. 295, and is very similar to the machine by Siemens; with this difference, that in Siemens' machine the armature rotates and the electro-magnets are fixed, whilst in this machine the armature is fixed and the magnets rotate. Upon the shaft a strong perforated disc is fixed, and the electro-magnets are arranged on the circumference of

this disc. The coiling of the magnets is the same as in Siemens' generator, *i.e.* a current flowing through the coils makes the succeeding poles alternately north and south magnetic poles. An auxiliary machine supplies the electro-magnets with their current. Within the supports, which carry the bearings for the shaft, two circular supports are fastened to the sole-plate; each of these supports consists

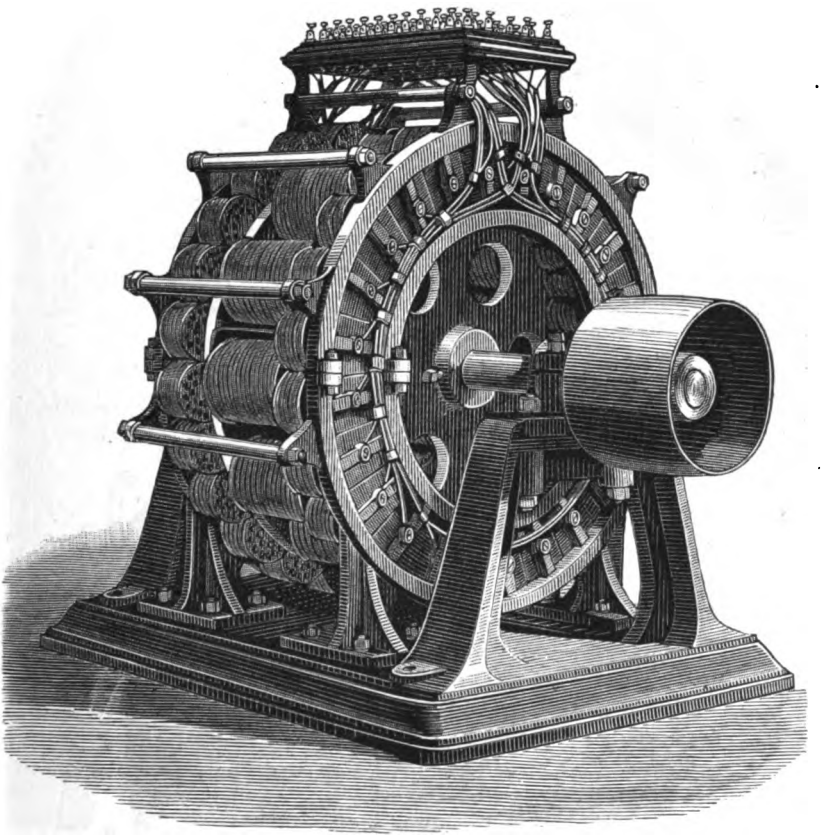


Fig. 295.—The Gérard Alternating Machine.

of semicircular rings, which have their ends screwed well together. The rings of these side supports are further connected by a number of bars, so as to give greater firmness. The cross section of the armature coils, which are fastened to these circular supports, would be oval in shape, and the wire ends of each coil are conducted to a board on the top of the machine, which is furnished with binding screws. This arrangement allows the coils to be joined up in different ways, so that the machine may be used for different purposes, requiring either tension or quantity. Fig. 296 represents a still larger machine by the same constructor,

which is coupled with a Corliss steam-engine of 250 horse-power. Here, too, the coils of the armature are fixed upon the rims of two fixed wheels, between

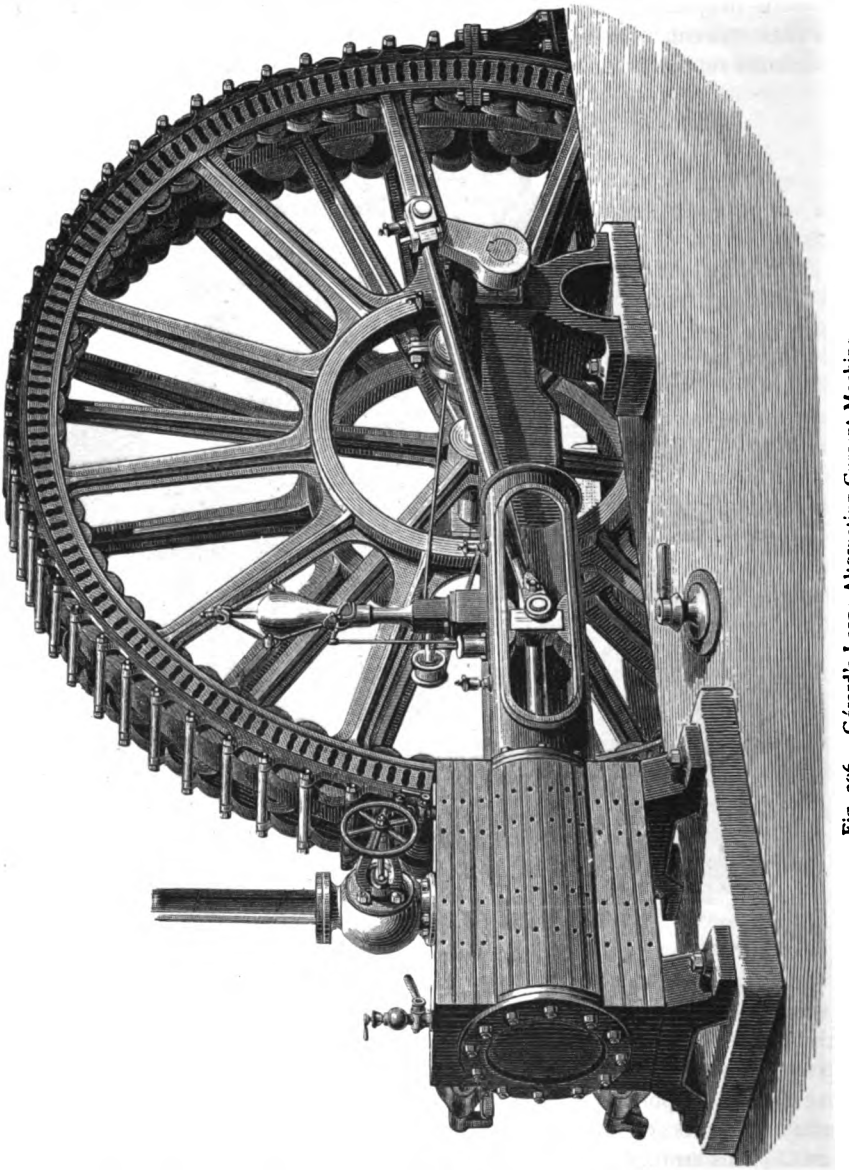


Fig. 296.—Gérard's Large Alternating Current Machine.

which the wheel with the electro-magnets forming the fly-wheel of the steam-engine rotates. This machine is intended to supply 1,000 arc-lamps or 3,000 incandescents.

Gordon's Generator.—Gordon's alternating current machine is still larger. It was constructed by the Telegraph Construction and Maintenance Company, Greenwich. The electro-magnets in this machine also rotate, whilst the armature is fixed. It is represented in Fig. 297. One half of the figure represents a cross section, the other half an end view. The shaft w moves in two

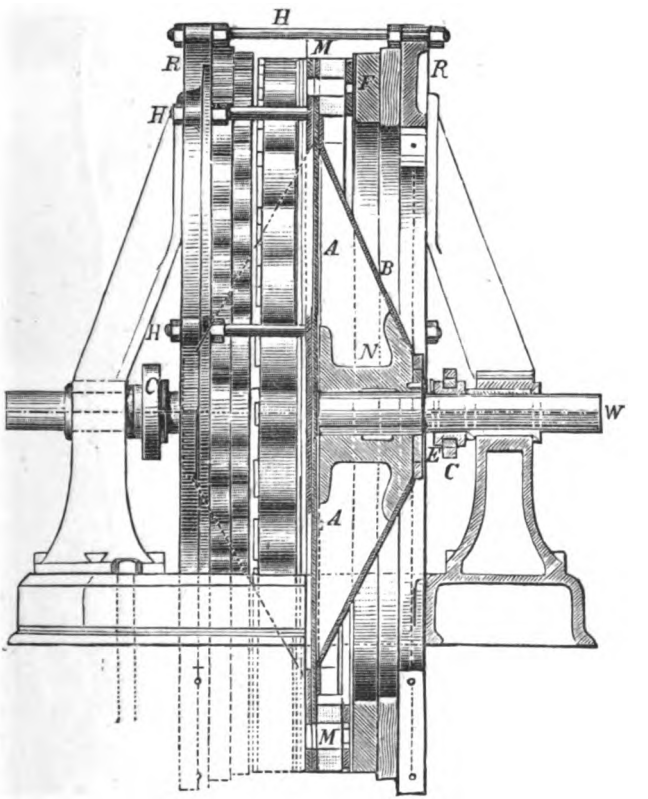


Fig. 297.—The Gordon Generator.

bronze bearings, and carries in the middle two wrought-iron discs A, of 2·67 metres diameter. To each of these a flat cone B of strong sheet iron is riveted; the vertex of this is fastened to a kind of nave N attached to the shaft. The cone B serves the purpose of stiffening the disc A. In the space between the nave and axle-bearing, rings E are fixed upon the shaft. These rings have grooves in them filled with vulcanite, to carry and insulate the contact rings C. The rings C are made of bronze, and are intended, together with the copper brushes which slide upon them, to conduct the current into the electro-magnets. The current for this purpose is supplied by two auxiliary Bürgin

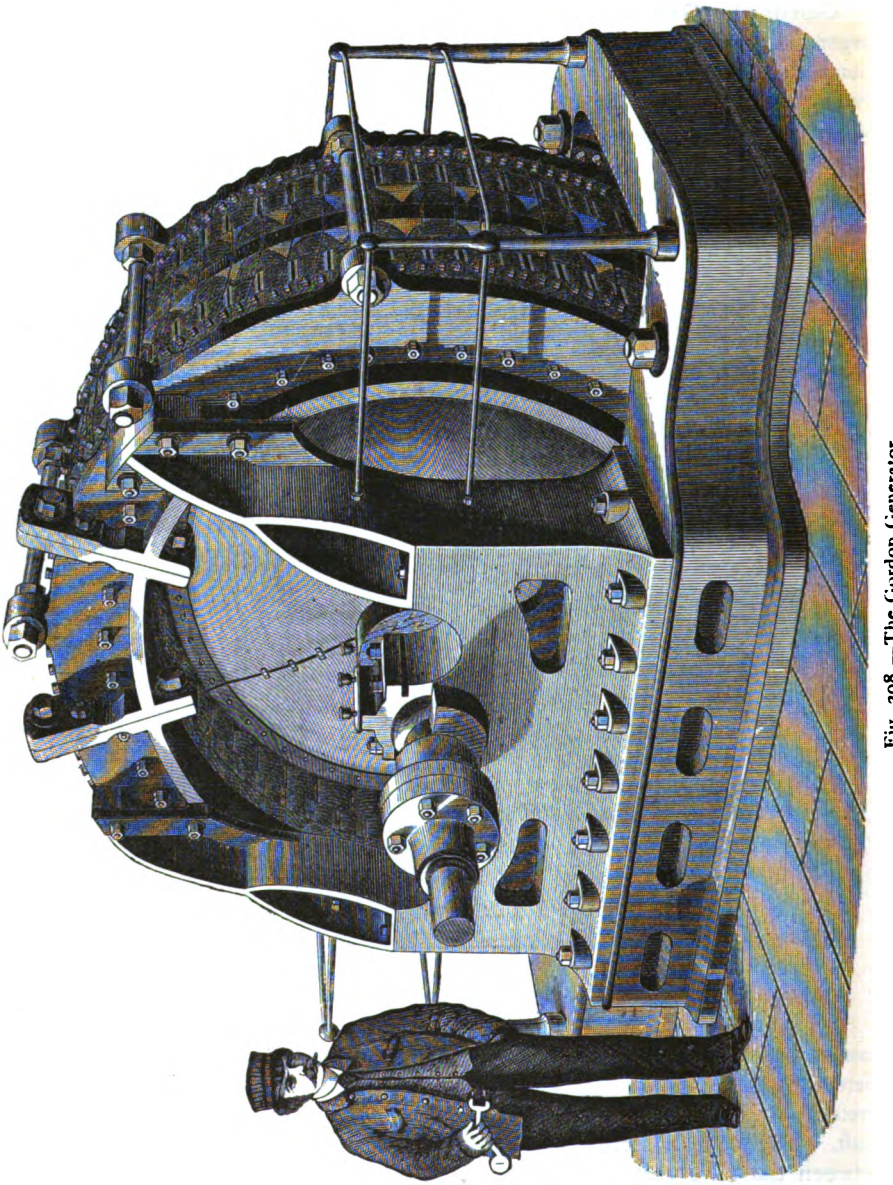


Fig. 298.—The Gordon Generator.

machines. Each of the discs A carries on its circumference thirty-two electro-magnets, the coils of which have currents passing through them in such a manner that a north and south pole in the circle recur alternately. The magnets

are put in series at both sides of the armature wheel A. The magnet cores are made of wrought iron and penetrate the combined discs, so that one pole is on one side of the disc and the other pole on the other side. The insulated wire is wound on brass spools which are slipped over the cores. Upon the massive cast-iron supports, strong iron rings R are fastened, and held in position by the horizontal bars H. At the inside of each cast-iron ring sixty-four induction coils F are fixed, and are insulated from the ring by means of wooden plates. The total number of induction coils is, therefore, 128. The coils are grouped into two different circuits, to distinguish which the coils are painted alternately red and blue. The iron cores of the coils are wedge-shaped, and the insulated copper wire of the spools has a cross section of 4·7 millimetres. The coils are fixed by means of their cores to the iron rings, from which they are insulated by the wooden pieces mentioned before. The coils have the sides facing the rotating magnets covered and protected by German silver sheets; from which the electro-magnets are only three millimetres distant. The copper wires have a double coating; every coil is dipped in shellac varnish, and then dried at a high temperature, and finally painted with asbestos paint. There are, in all, 128 stationary bobbins (64 on each side), and they are acted on inductively by 32 electro-magnets having 64 poles, so that there are twice as many bobbins as magnet poles. If the machine had the same number of bobbins as electro-magnetic poles, the inductive action of one bobbin on the next one would be so strong as to materially reduce the efficiency of the machine. The rotating discs, with their electro-magnets, weigh nearly 7 tons. The total weight of the machine is nearly 18 tons.

On looking at Fig. 298 we see that the rings carrying the induction coils consist of several pieces; the small middle piece at the upper portion of the ring, placed between the two side segments, is easily removed, so as to allow the magnets to be repaired if they become damaged. The following is a published report of the results obtained with this machine. The generator supplying the electro-magnets with current was set in motion by a 5 horse-power steam-engine, the current thus obtained being equal to twenty-five amperes. The large steam-engine which worked the alternating current machine required 170 horse-power—that is, for principal and auxiliary generators, 175 horse-power were required. The alternating current machine furnished a current having a potential of 103 volts, and supplied 1,400 Swan lamps in two rows. Each lamp was estimated to have a resistance of thirty ohms, and to give a light equal to twenty-two or twenty-three candles. The total resistance of the machine was equal to 0·0985 ohm, and the resistance of the circuit to 0·006 ohm, which gives a current of 1,030 amperes. This amounts to 180 candles for each horse-power. The proportion of electrical work done by the alternating current machine, as measured in the cylinder of the steam-engine, was equal to 0·816.

The Ganz Generator.—The steam light machine, by Ganz and Co., was constructed by Mechwart and Zipernowsky. The generator that supplies the electros with current, the light machine, and the steam-engine are connected

with each other in such a manner that all three together may be regarded as forming only one machine. All the rotating portions are fixed to the fly-wheel of the steam-engine, so that nowhere is any belt or coupling used. Figs. 299 and 300 represent the machine in perspective and in section. The movable

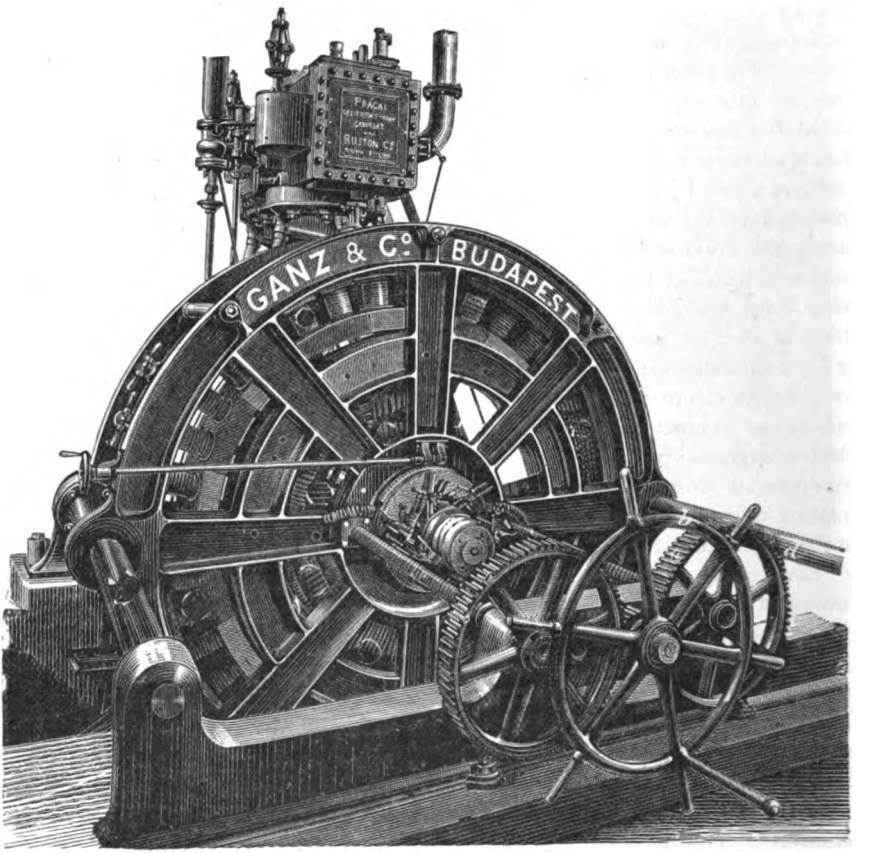


Fig. 299.—The Ganz Generator.

portions of the machine are the electro-magnets of the alternating current generator, and the Gramme ring of the auxiliary machine. On the circumference of the fly-wheel B B belonging to the steam-engine, thirty-two electro-magnets *m* are fastened. These rotate so that their shoes pass very close to the induction coils *r r* (also thirty-six in number), which are fastened to the inside of the fixed drum A A. The drum has iron wire wound round it, and is supported by an iron frame. The current is so conducted through the coils of the electro-magnets

that the magnetic polarities continually change; therefore alternating currents will be generated in the coils of the drum. The inducing machine consists of the Gramme ring R R, which is fastened to the fly-wheel of the steam-engine, and

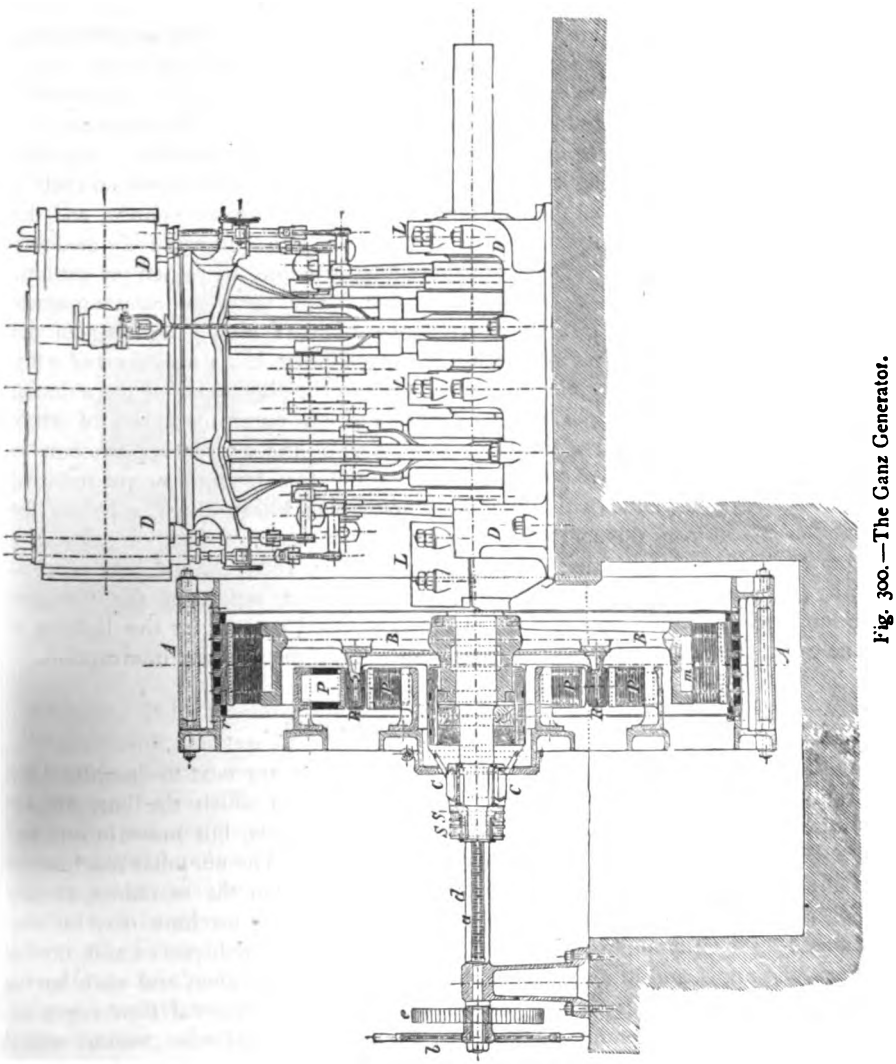


Fig. 300.—The Ganz Generator.

the inducing electro-magnets P (twelve inside and twelve outside the ring) come close to the ring, and are fastened to the fixed drum. The auxiliary generator thus takes up the middle portion of the whole. The currents induced in the Gramme

ring flow from commutator C through brushes to the sliding rings S S_1, and then to the electro-magnets of the alternating current generator. The diameter of the Gramme ring is 1·5 metres, and the diameter of the fixed drum which carries the induction coils of the alternating current generator is three metres. For the light machine a compound steam-engine D is used. The steam-engine makes 180 revolutions per minute, and exerts 150 horse-power. The whole machine possesses only three bearings L. In the event of damage the drum may be moved out of its position by means of the wheels *b a d*, so as to lay free the fly-wheel with the electro-magnets and the Gramme ring. The little wheel to the left of the drawing serves the purpose of adjusting the brushes. This connection of a steam and light machine has the following advantages: no belt is required for transmission, the machine requires very little attendance, and the bearings are not so soon worn out, as they rotate with comparatively moderate velocity. The thirty-six coils of the alternating machine are joined for quantity, and have a resistance of only 0·0039 ohm. The thirty-six electro-magnets joined in six circuits possess a resistance of 0·41 ohm; the ring of the inducing machine, with its six brushes at the collector, has a resistance of 0·165 ohm, and the twenty-four electro-magnet coils in the six circuits of the inducing machine 0·24 ohm. By 180 revolutions, and an outer resistance of 0·038 ohm, the difference of potential at the poles of the alternating machine is 57·6 volts. Difference of potential between the two brushes on the inducing machine = 36·4 volts (with outer resistance 0·24 ohm), which gives for the total electrical work done 140 horse-power, 85 per cent. of which is utilised by the electrical work. During the exhibition (Vienna, 1883) the machine supplied 1,035 incandescent lamps (Swan). According to a report of the "Wiener electro-technischen Vereines," this machine supplied current for the lighting of the exhibition theatre during the exhibition without the slightest interruption.

UNI-POLAR MACHINES.

Ball's Machine.—The group of machines we are next to describe differ from the foregoing in this respect: the conductors in which the currents are induced do not alternately pass different magnetic fields, but move in one and the same field. They are termed uni-polar machines. The uni-polar machine by Ball (Fig. 301) is, as regards plan, intermediate between the machines already described and the strictly uni-polar machines. Ball's machine may be considered as a Gramme machine with differently arranged pole-pieces and double rings, the upper and lower poles not being one under the other, and each having a ring of its own. Upon the vertical side supports horizontal iron cores are fastened, as in the Gramme machine, and have insulated wire wound round them almost through their whole length; the turns are arranged so that when a current is passing similar poles come together at the top pole-pieces, and similar poles likewise at the bottom. These electro-magnets, together with the two supports, constitute two horse-shoe magnets, the arms of which are unequal in length, and

the similar poles of which face each other. The two pole-pieces, therefore, have opposite magnetic polarity. One pole-piece surrounds the upper portion of a Gramme ring, the other pole-piece the lower portion of a second Gramme ring. Each of the Gramme rings is fastened to a separate shaft, and they move in opposite directions. The machine, therefore, resembles two coupled Gramme machines, although the rings are influenced at each side by only one magnet pole. In the half of the ring nearest the electro-magnet pole dissimilar magnetism is produced, and in the half opposite, similar magnetism to that of the adjacent pole. The coils, therefore, experience inducing effects through south as well as north magnetism. That this is so may be seen by simply adjusting the brushes, which require to be placed as in the ordinary Gramme

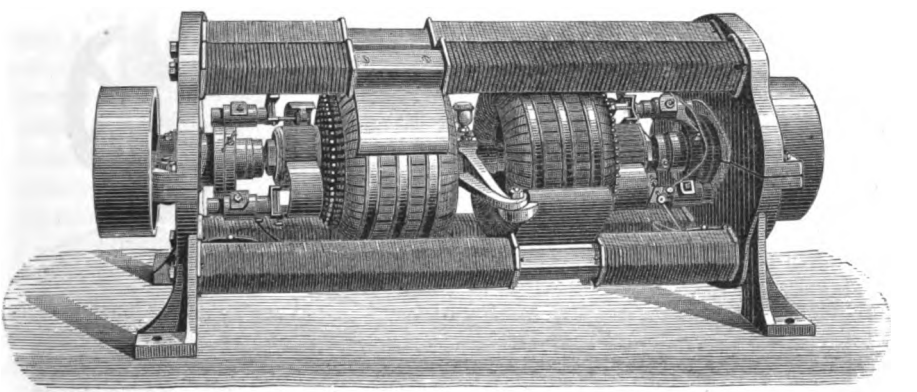


Fig. 301.—Ball's Uni-polar Dynamo.

machine. Ball's machine differs in this respect from the Gramme machine: that in the former, for two armatures, only two magnetic fields are needed, whilst the Gramme machine requires for each armature two such fields. Ball's machine is less heated than a Gramme of the same power, as the same quantity of wire is wound upon two instead of upon one ring. It seems that in order to produce two powerful poles in the ring one magnetic field is sufficient, and such an arrangement has the advantage of suppressing Foucault or eddy currents. Robert Sabine, of London, who has examined Ball's machine, made the following report: Strength of current = 15 amperes, difference of potential at the poles = 195 volts, resistance of the machine = 4·5 ohms, when the machine made from 1,650 to 1,715 revolutions per minute. The work done by the dynamo machine = 5·68 horse-power, of which 3·92 horse-power come to the external, and 1·35 horse-power to the internal circuit. The total amount of electrical work done = 5·27 horse-power, which gives for the total electric effect 0·92.

Conditions of Maximum Induction.—In the first portion of this work it has been mentioned, that in order to produce powerful currents it is not

necessary to vary the strength of the magnetic fields in which the conductor moves. For the purpose, motion of a conductor in a magnetic field is sufficient, provided the direction of motion is not the same as the direction which the lines of force have, or in the case of a closed circuit, provided the lines are not cut by one side at the same rate and in the same direction as they are cut by the other side. A ring moving in a uniform field parallel to itself would have no current. The induction will be most powerful when the lines of force are cut at right angles in opposite directions by the two sides of the circuit. When the direction of motion of the conductor takes place at right angles to the direction of the lines of force, the direction of the induced

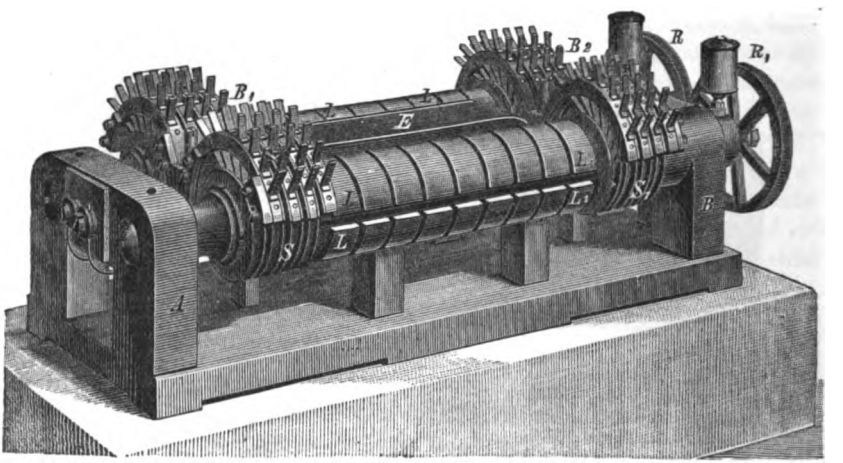


Fig. 302.—Siemens' Uni-polar Dynamo.

currents will be at right angles to the direction of motion. In this case, owing to this motion of the wire through the magnetic lines of force, a current will be induced in the wire which flows parallel to the longitudinal axis of the magnet. All three directions—viz., direction of the lines of force, direction of motion, and direction of the length of wire—stand at right angles to each other, like the three adjacent edges of a cube. These conditions exist, for instance, in Siemens' drum armature, although the latter rotates in alternating magnetic fields. As the change of poles is always accompanied by the loss of energy, to avoid this change of polarity as much as possible seems advantageous. That is the reason why some continuous current and alternating current machines constructed recently have no iron cores. The armatures in the machines by Elphinstone and by Thomson are also free from iron, although the change of current in the armature is still left.

Siemens' Uni-polar Machine.—No change of the magnetic field nor change in the direction of the induced current takes place in the uni-polar

machine by Siemens, shown in Fig. 302. The electro-magnet E is fixed horizontally, and has at both sides cylindrically bent pole-pieces L L_1; each of the spaces formed in this manner is a magnetic field of only one kind. Split cylinders of copper, which have their bearings upon the supports A and B, rotate in these hollow spaces, and constitute the armatures. Each of the cylinders is made of four copper strips, insulated and parallel to the longitudinal direction of the axis, and each end of these strips is connected with one of the sliding rings s s_1. The brushes B_1 B_2 conduct the induced currents from the copper. The two armatures are put into motion by means of the wheels R R_1 and a belt.

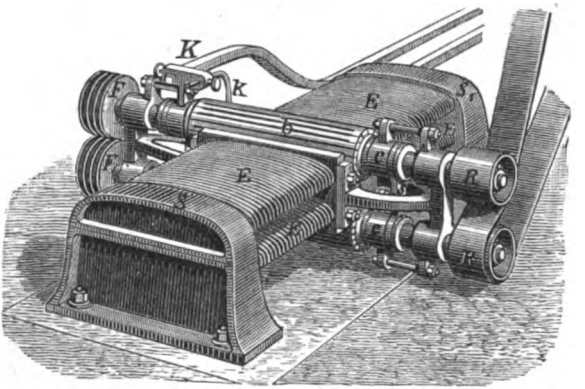


Fig. 303.—Ferraris' Uni-polar Dynamo.

In this machine the copper strips of the armature are always at right angles to the lines of force; the direction of the currents will therefore remain the

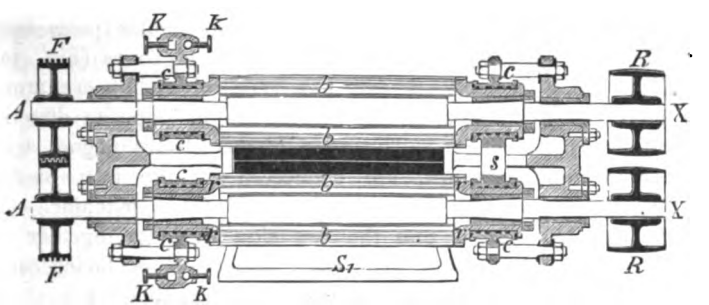


Fig. 304.—Ferraris' Uni-polar Dynamo.

same, as the strips always rotate in one and the same magnetic field. The direction of the currents corresponds with the longitudinal direction of the strips, which will be either from left to right or right to left, depending upon the direction of motion of the armature.

Although Siemens' uni-polar machine has not yet been put to practical use, it has served as a model for the construction of E. Ferraris' uni-polar machine. Ferraris, the director of mines, in constructing this machine, aimed at supplying a generator of electricity suitable for electro-chemical purposes. We shall take this subject up again farther on, with the view of showing that by utilising

electrical currents for chemical and metallurgical purposes a vast field of enterprise is yet to be opened.

Uni-polar Machine by Ferraris.—The uni-polar machine by Ferraris is represented in Figs. 303, 304, and 305. The machine, like that of Siemens, possesses two armatures which are insulated and fastened upon the axes A X, and consist of copper bars *b b*, running parallel to the axes, the ends of which are screwed to the discs *r r*, and are connected with the rings which bear the collectors *c c*. By making the cylinder of separate bars, transverse currents are avoided. On one side of the cylinder the bearings are connected by the piece *s*, whilst on the opposite side are the binding screws *k k*. The copper bars of both armatures may therefore either be joined in series or parallel. The binding screws *k k* conduct the induced currents into the outer circuit; with the help of the binding screws K K a branch current may be shunted into the coils of the electro-magnets E. As the bearings *c c* are inserted in the circuit of the machine, none of the ordinary lubricators can be used, as they would prevent the passage of the currents; this difficulty has been overcome by using inside the bearings lubricators which consist of an alloy of thallium. The electro-magnets are flat, and are arranged in the same manner as in the drum machine of Siemens; both upper and lower arms have their similar poles facing each other, and connected by means of semi-cylindrical shoes (Fig. 305); the cavities of the latter, however, do not face each other, but are arranged on opposite sides. Each shoe, therefore, surrounds in opposite directions one-half of an armature cylinder. The ends of the electro-magnet arms which are away from the armatures, are connected by the iron pieces which form at the same time the side supports $S S_1$ of the machine. The four arms of the electro-magnets and the two side supports together make up two horse-shoe magnets, which have their similar poles facing each other. The shafts of the armatures have at one end the belt wheels R R, at the other end the toothed wheels F F, for the purpose of transmitting the motion from one cylinder to the other. The toothed wheels and the shaft being made of soft iron, form together a kind of horse-shoe, or armature X F F X (Fig. 304), of the electro-magnets, which causes concentration of the lines of force. For the same purpose the space between the cylinder jacket and the axis is partly filled up with iron discs. The circuit of the magnets may be arranged as a shunt to the circuit of the armatures by means of the clamps K K. Each magnet, however, has a commutator, by means of which the arms of the electrodes may be joined up in series or parallel, according as the purpose for which the current is to be used requires tension or quantity. By means of these commutators different resistances may

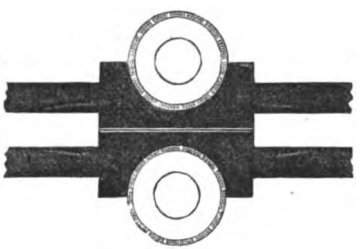
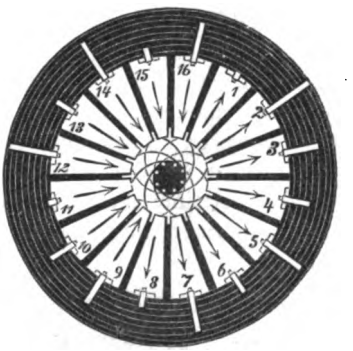


Fig. 305.—Ferraris' Uni-polar Dynamo.

be inserted, and the coils of the magnets may be further connected with an auxiliary machine. The machine may also be used as an ordinary dynamo-electrical machine, for its construction allows of the separation of the dissimilar poles of its magnets so as to make room for an armature of either the Siemens, Edison, or Bürgin pattern. The upper cylinder rotates *above* one pole in one direction, the lower cylinder *below* the *opposite* pole in the *opposite* direction. Two of these changes neutralise one another so that the three are equivalent to one. Hence the currents induced in the copper bars of the upper cylinder must have the opposite direction to the currents in the lower cylinder. As both are connected by the piece *s* on one side, this piece and the two cylinders form part of the same circuit, in which all the induced currents must have a continuous direction, therefore positive electricity will be supplied from one binding screw *k*, and negative from the other.



End View of Edison's Disc Armature.

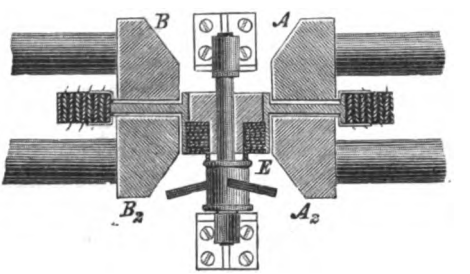


Fig. 306.—Edison's Disc Dynamo.

Edison's Disc Dynamo.—We may mention here one more machine, for which Edison has taken out a patent. From a practical point of view this machine is as yet of no importance, but may be considered as the first of a kind constructed on the basis of Foucault's rotation apparatus (page 191). A copper disc rotating between the poles of a powerful magnet has the induced currents flowing in radial directions. Foucault's apparatus is of no use for generating electrical currents for practical purposes: first, because not sufficient electricity can be produced; secondly, because the arrangement for the conduction of the induced currents at the surface of the disc is not of a very practical character; lastly, transverse currents will make their appearance in the solid disc. Edison has attempted to avoid these drawbacks in his machine, shown in Fig. 306. Instead of using only one horse-shoe magnet, he uses two, the shoes or pole-pieces of which A A_2 and B B_2 he arranges as near each other as possible. The copper disc which has to rotate in the powerful magnetic fields thus produced does not consist of a solid disc, but is composed of sixteen radial bars or spokes (numbered 1 to 16), with an insulating sub-

stance between, and connected at the outer ends by concentric hoops. When this disc is made to rotate between the poles of the electro-magnets, currents will be induced that flow radially, oscillating in two directions. As the lines of force in the two magnetic fields also have opposite directions, in one half of the disc their direction will be centripetal, in the other half centrifugal. In order to conduct away the currents induced in the copper strips, their inner ends are connected with a commutator, while, as we have said, their outer ends are connected with eight copper hoops, insulated from each other in such a manner that the whole armature represents a closed circuit. The currents in the two armatures are induced, as in the Gramme ring, in parallel branches. In this armature, however, no continued change of the magnetic polarities takes place, as no magnetism is induced. The avoidance of the change of polarities in the armature is certainly an improvement. Yet Edison's machine can only be regarded as an interesting experiment.

CONSTRUCTION AND WORKING CONDITIONS OF MACHINES.

Difficulties of Classification.—Our subject is far from being exhausted by the description of the foregoing machines. We have purposely paid attention only to those machines that show marked differences as regards the principles on which they are constructed, mechanical execution, etc. It is not possible to secure a rigorous classification, as the distinguishing features of the different types are not sufficiently independent. Machines, for instance, may be divided into continuous current machines and alternating current machines. But in this case the alternating current and continuous current machines of Siemens would have had to be treated separately, which would scarcely seem desirable, on account of their similarity. Again, the cylindrical and drum machines, and likewise those which are provided with the Pacinotti or a similarly constructed ring, also generate alternating currents, and the introduction of a commutator is sufficient to cause the currents to flow in the same direction through the exterior circuit.

In the uni-polar machine of Ferraris, all the conditions of a continuous current machine are satisfied. It would, for this reason, not be satisfactory to group machines according as they are magneto-electric or dynamo-electric, as electro-magnets of one and the same machine may be induced in different ways, according to the work required of the machine.

Recapitulation of Common Features.—We will now trace certain points of resemblance in all these machines, and show their agreement with certain general laws. We will then examine the differences that make one particular kind of machine more suitable for any given kind of work than another.

All dynamos agree with the law that *the induced currents in all cases of electro-magnetic inductions have such a direction that their reaction tends to stop the motion that produces them* (Lenz's law).

In all machines the generation of electric currents is effected by the wires not

containing currents, and magnet fields, constantly changing their relative positions, by means of one portion of the machine (armature or electro-magnets) being kept in motion. In all cases the electric currents are supplied as the equivalent of the mechanical work done by the motor which keeps the current machine in motion, less a certain percentage, varying in different machines, which is unavoidably lost or dissipated. Little power is required to set an electric machine in motion and to maintain it in motion when the dynamo-electric principle is satisfied, and the outer circuit is unbroken. Where the exterior circuit is broken, the dynamo-electric machine is unable of itself to produce any currents at all, as the currents induced in the armature by the residual magnetism would be so weak as to be prevented by the intermission of the circuit from flowing into the coils of the electros. In the case of a machine furnished with permanent steel magnets, or with electro-magnets which are fed from an independent source of electricity, currents are generated in their armatures even when the outer circuit is interrupted. In order to maintain the motion of these machines with a closed outer circuit, a much greater expenditure of power is required. We may easily convince ourselves that this is the case by making experiments with little hand machines of this kind; we shall find that for the first few turns of such a dynamo-electric machine very little exertion is required, but this exertion has to be increased in proportion as the strength of the current increases. This proves, then, that by generating currents in the armature, an opposing force is called into existence, and tends to retard the rotating parts of the machine.

Let us now consider the resistance produced by the machine itself. In all dynamos, either the bobbins move in the presence of magnetic poles, or magnets move in the neighbourhood of coils in which currents circulate. We know that the coil and magnet will either attract or repel each other, according as the ampere and induced currents are opposite or parallel as regards their directions. An action and reaction, therefore, take place in every machine between the fixed and rotating portions. There are only two cases possible: The generated force will either tend to move the rotating portion in the direction in which it is moved by the moving power—*e.g.* the steam-engine—or this force will tend to move the rotating portion in the opposite direction. In other words, it either assists or opposes the motor. Whether the one or the other takes place we can ascertain from the diagram of the machine, as we have already done in the case of the Gramme ring. In fact, experience derived from mechanical observations of other kind tells us that the generated force must oppose the motion. If this were otherwise the machine once started would require no external moving power to sustain its motion—a result which would be contrary to the mechanical law that "perpetual motion is impossible." This retarding force will occur in every machine, whatever its construction may be. We shall find that in the conductors or portions of the conductors which are brought near a magnetic pole, currents are produced which are opposite to the direction of the ampere currents of the magnetic pole, and hence these currents will be repelled by

this pole. Conductors moving away from a magnetic pole will have the direction of their induced currents parallel to the ampere currents of that pole; the latter, therefore, will try to retain the conductor—*i.e.*, the whole system is influenced by a force which tries to move it in a direction opposite to the direction it is moved by the outer force. This will explain why an electric machine requires a constant supply of motive power to keep it in motion, and how it is that the amount required will vary proportionally to the current produced by the machine. We hardly need remark that a portion of the work done by the motor is used for overcoming the friction in the different parts of the machine, etc. The greater portion of the work, however, is converted into electricity by overcoming the force of attraction or repulsion between the movable and fixed portions of the machine. This force of attraction (or repulsion) manifests itself as long as the machine is in motion, becoming stronger or weaker in the same proportion as the current alters its strength; work, therefore, will be done by the electric machine, and the amount of work will vary with the increase or decrease of current. The behaviour of the electric machine gives a beautiful example of the law of the conservation of energy, which tells us that the work done by any machine will be proportional to the work expended on it.

Ohm's Law applies to all Machines.—We know the law which determines the strength of any current produced by a machine. Whenever there is a difference of potential E between two points connected by a conductor of resistance R, no matter by what process E is produced, the current C in the conductor will be given by Ohm's law, $C = \frac{E}{R}$. In order, then, to calculate the strength of the current, it is necessary to know the E. M. F., and also the total resistance. We must inquire, therefore, upon what conditions these two factors depend. The E. M. F. force must be the greater, the greater the induction in the wires; it must depend, therefore, upon the strength of the magnets and the distance of the magnet poles from the coils. The E. M. F. will be increased when the strength of the magnets is increased, and when their distance from the coils is diminished. In constructing a machine, therefore, care ought to be taken that magnets and armature are as close as possible to each other. Machines possessing steel magnets the strength of which remains constant will also have the E. M. F. constant. The E. M. F. will also remain constant when the magnetism of the machine is induced by an independent source of electricity. Just as the E. M. F. of a galvanic battery depends not only upon the difference of potential between the bodies brought into contact, but also upon the number of such contacts—*i.e.*, the number of elements joined to each other—the E. M. F. of a machine will vary with the number of turns in the armature. Other conditions being equal, the E. M. F. is directly proportional to the number of turns in the armature coils. The E. M. F. of an induced current, as we know, is greater the faster the current moves; the E. M. F. of a machine, then, will be greater, the greater the velocity, and will also be directly proportional

to the number of revolutions the machine makes in a given time. The E. M. F. of a magneto-electric machine, *i.e.* a machine that possesses steel magnets, or the magnetism of which is induced by an independent, but constant, source of electricity, will depend only upon the intensity of magnets, number of turns in the coils, and velocity. We will now express these conditions by means of an equation.

Relation of Speed and E. M. F.—*Faraday's principle and Maxwell's rule* give us an easy method of taking account of the intensity of the magnetic field, no matter how it is produced. Let M be the intensity of the field, then we imagine M lines of force to be drawn through a unit of area all over the field where this is the intensity. Let a single coil of area A rotate about an axis at right angles to the direction of the lines of force, then the number of lines passing through the ring has a maximum of M A and minimum of o.

If the area starts with its plane parallel to the lines of force, in the first quarter of a revolution M A lines are taken in positively. In the second quarter of a revolution M A lines are taken out. In the third quarter of a revolution M A lines are taken in negatively. In the fourth quarter of a revolution M A lines are taken out.

Hence, the average electromotive force for one revolution is 4 M A, and if there are n revolutions per second, and E be the average electromotive force,

$$E = 4\,n\,M\,A.$$

This formula is also true for a coil of any number of loops if A, instead of being the area of one loop, is the sum of the areas of all the loops.

Let E be the whole electromotive force, and let e be the difference of potential, or the electro-motive force between the terminals to which the exterior circuit is attached. Then e is less than E, for part of the electromotive force is expended in overcoming the resistance in the armature.

Let R be the resistance of the outer circuit, and r that of the armature, also let c be the strength of a current. Then Ohm's law gives us :

$$E = c\ (r + R)$$
$$e = c\ R$$

and therefore $E : e :: r + R : r$;

$$\text{or } E = \frac{R + r)\,e}{R}. \text{ and } e = \frac{4\,A\,n\,M\,R}{R + r}.$$

The Efficiency of a Magneto Machine.—From the analogy of the steam-engine, the ratio of the energy given out by the machine to the whole energy which it consumes is termed the *electric efficiency*. Some of the energy is absorbed in the interior, so that the useful energy of the exterior circuit is less than the whole. The energy yielded per second, measured in watts, is for the whole circuit C (amperes) × E (volts), and for the exterior circuit C (amperes) × e (volts).

$$\text{Hence the electric efficiency} = \frac{\text{useful energy}}{\text{total energy}} = \frac{C\,e}{C\,E} = \frac{e}{E} = \frac{R}{R+r}.$$

But the total energy developed in the machine, both useful and useless, may not be equal to that of the steam-engine driving it, hence we must distinguish between

$$\text{the gross efficiency} = \frac{\text{gross electrical energy}}{\text{work done by the driving engine}},$$

$$\text{and the net efficiency} = \frac{\text{useful electric energy}}{\text{work done by the driving engine}}.$$

If the horse-power of the engine per second is W, that reduced to watts is 746 W; hence

$$\text{gross efficiency} = \frac{E\,C}{746\,W},$$

$$\text{net efficiency} = \frac{e\,C}{746\,W},$$

and therefore net efficiency = gross efficiency × electrical efficiency.

The Series Dynamo.

Here also $E = 4\,n\,A\,M$,

but M depends on (or is a function of) the strength of current C, and the total resistance (outer circuit R, armature r, and magnet coil m). It also depends on the quality of the iron core and the size and shape of the magnets. When the magnets are not worked in a strength near the point of saturation, M varies as C varies, and we may introduce this fact into the equation in the following manner. By combining the equation with Ohm's law, we have

$$C = \frac{E}{R} = \frac{4\,A\,n\,M}{R}.$$

The fact that the effective magnetism or strength of field M alters with the current is expressed by writing

$$M = \text{a function of C or} = f(C).$$

$$\text{And as } \frac{C}{M} = \frac{4\,A\,n}{R},$$

$$\text{therefore } \frac{C}{f(C)} = \frac{4\,A\,n}{R}.$$

Here the 4 A is constant for the same machine, and therefore $\frac{n}{R}$ is a function of C. If we could determine what function, and solve the equation for C, we should, of course, obtain C on one side of the equation and terms involving $\frac{n}{R}$ on the other. That is to say, we should have C as a function of $\frac{n}{R}$. Therefore *the strength of the current is only a function of the ratio of the number of rotations per second n to the total resistance* R.

We now have three equations connecting five quantities:

1. Ohm's law $E = C R$.
2. The magnetic equation $E = 4 A n M$.
3. The current equation $C =$ a function of $\frac{4 A n}{R}$.

Graphic Diagrams.—In order to estimate the efficiency of a machine, the best means is to plot out a diagram of measurements on squared paper, *i.e.* to make a graphical representation of the quantities which are characteristic of the machine. This plan can be adopted whenever there are two quantities that vary together, so that one may be said to be a function of the other. Now we have several equations which furnish us with such quantities, so that we may draw several curves for any machine. We might, for instance, plot out a curve on the basis of Ohm's law. For this purpose the machine would have to be set in motion and regulated so that it rotates with a uniform speed, and determinations would have to be made for a certain number of revolutions.

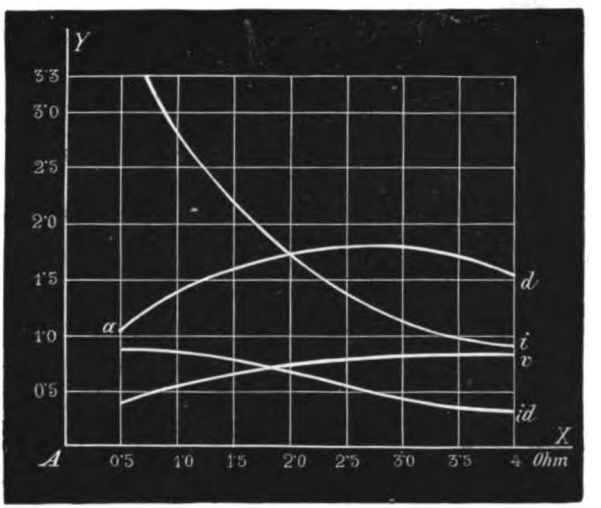


Fig. 307.—Diagrams for a Dynamo-Electric Machine.

The resistance in the outer circuit may be increased in succession by half an ohm, the strength of the current (*c*) and the difference of potentials (*e*) for the same speed being measured with each resistance. A graphical representation for the variations of potentials is thus obtained for resistances of 0·5, 1, 1·5, 2, etc., ohms. The resistances are marked along the line A X (Fig. 307), and the potentials on the line A Y, which is drawn perpendicular to A X. If now the points thus plotted out be joined, as shown in the figure, the curve *a d* will represent graphically the potentials for different resistances. The point *a* has been determined in the following manner: By a resistance of 0·5 ohm and the desired speed, the difference of potentials was taken, and happened to be 1·. From the point 1· in the line A Y a straight line (or ordinate) 1· *a* is drawn, and from point 0·5 in the line A X the straight line or abscissa 0·5 *a* is drawn. At *a*, where the two lines cut each other, a point of the curve is obtained. As many more points of the curve as are required may be obtained in a similar manner.

There are three other curves represented in the figure, having for abscissæ in all cases the successive resistances.

Curve *i* has for ordinates strength of currents.
Curve *v* has for ordinates the utilised resistances.
Curve *i d* has for ordinates the ratio of C to E.

From these curves the efficiency of a dynamo-electrical machine may be determined. We find, for instance, *i d* has its maximum (*i.e.* the curve has the highest point) when the utilised resistance (for instance, the inserted lamps) is equal to half the total resistance.

Much may be learnt of the theory of machines in general, as well as of the qualities of a particular machine, by a study of two of these curves together. The general method of representing the theory by means of graphic diagrams was developed by Professors Ayrton and Perry, and has been worked out by Fröhlich and by Deprez. As the curves are drawn from observation and actual measurements, they serve both as checks and illustrations of conclusions arrived at by means of mathematical analysis, and have led to other conclusions which are not to be found by other means.

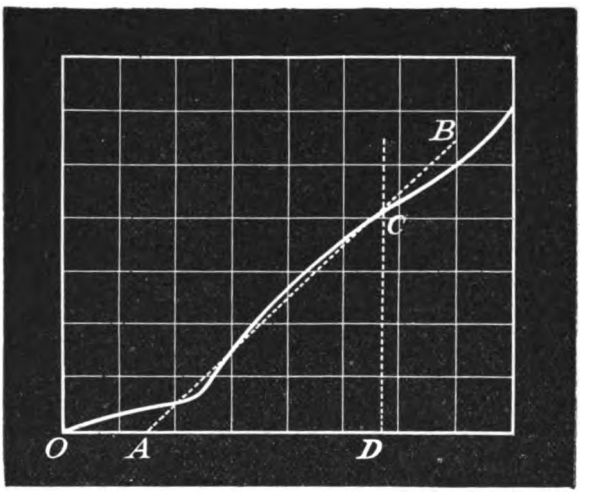


Fig. 308.—Fröhlich's Current Curve.

Fröhlich's Current Curve.—We may plot out a curve in connection with each of the equations above, by taking horizontal distances for different values of one of the two quantities involved, and vertical distances for the corresponding values of the other quantity. When we do this with C and $\frac{n}{R}$ in the third equation we obtain *Fröhlich's Current Curve.* To get this curve we work the generator under investigation at as many different rates as possible, inserting varied resistances and measuring the respective quantities of current. We then determine the ratio $\frac{n}{R}$ for each value of C. We set off the first on the horizontal line of reference, and the second C on the vertical line of reference in the way already described.

Now the current curve for a good machine, such as the Siemens generators, takes a form such as that in Fig. 308. For the portion of its course within the limits of currents of medium strength it is nearly a straight line. For this portion we may replace the current curve in the figure by the line A B, and we then find the theory of the machine much simplified.

$$\text{Let } C\,D = c,$$
$$O\,D = 4\,A\frac{n}{R},$$
$$\text{and } O\,A = a.$$

Now $\frac{C\,D}{A\,D}$ = the tangent of angle A. Let this be called m. Therefore

$$C\,D = m\,A\,D = m\,(o\,D - o\,A).$$
$$\text{Therefore } c = m\left(4\,A\frac{n}{R} - a\right);$$

an equation which will be true for currents neither very weak nor very strong. Now a curious result follows at once from this. As long as n, the number of rotations per second, is not too small, there will be a current; but when $\frac{4\,A\,n}{R}$ is not greater than a, the machine does no work. How is this? It is because with a small number of rotations the strength of current produced is not enough to give the field magnets a strength of magnetism exceeding the residual magnetism.

The revolutions the generator makes during the "start," and during which no effective current is generated, are called "dead revolutions." Hence, the constant a determines the "dead revolutions" of the armature.

The current curve exhibits the qualities of a machine, and the greater the number of observations plotted to draw it, the more exact will be the record. With a current curve and the three equations above referred to, all the circumstances of the action can be determined.

If it be known that a machine within certain limits gives a line nearly straight, then it is sufficient to make two sets of observations measuring the speed and current at two conditions within these limits. These will determine two points on the line, and give us the tangent of its inclination m and the point at which it cuts the horizontal line of reference or the length a.

Comparison of Magneto-Electric Machines and Dynamo-Electric Machines.—With a magneto-electric machine the strength of current is

$$c = 4\,A\,M\frac{n}{R}.$$

With a dynamo machine it is

$$c = m\left(4\,A\frac{n}{R} - a\right).$$

If the current curves be drawn for both machines, c being the ordinate and $\frac{n}{R}$ the

abscissa, the first will give a straight line from the origin O, the second a straight line from a point A in the horizontal axis (Fig. 308). The current with the dynamo will grow more rapidly than that of the magneto machine, as the speed increases, and the lines for the two machines will therefore intersect; that is to say, there is a speed for the two machines at which they give equal currents.

If the curves showing the relation between the strength of current and the resistance be drawn for both machines, each of the two curves will resemble that in the figure, and will cut each other at that resistance for which both machines give the same strength of current. The curves show that the effect of the "dead rotations" is to cause the dynamo machine to be much more sensitive to variations in resistance and velocity than is the magneto machine.

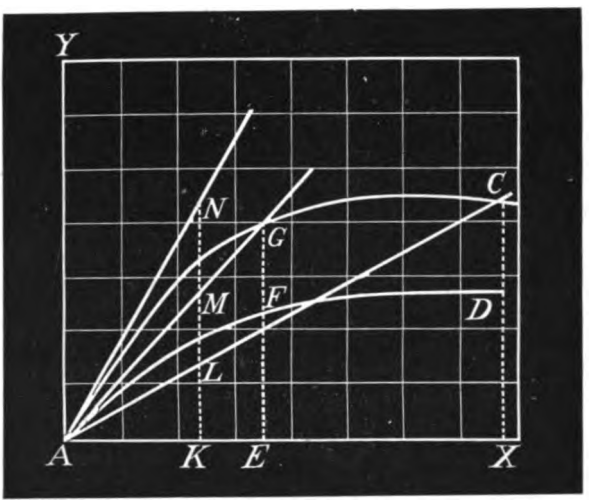


Fig. 309.— Deprez's Characteristic Curve.

Fröhlich's theory makes use, as a foundation, of the so-called current curve which represents the connection between the strength of the current and the velocity of rotation of the armature of the machine.

Deprez also starts from a similar curve to the curve *d* in Fig. 307, and which he calls the "characteristic curve."

Marcel Deprez's Characteristic Curve.—Take a dynamo machine and magnetise the field magnets by a current from another machine, *i.e.* let it be separately excited. Rotate the armature at a definite speed, and measure the electromotive force produced. If the exciting current round the field magnets be varied, the strengths of the magnetic field will be correspondingly varied, and a given electromotive force E at the terminals of the armature will correspond to each intensity C of the exciting current. During these changes the speed of rotation of the armature is supposed to be constant. If we now plot the different values of C in the exciting circuit, and E in the induced circuit, in the manner already described, a curve termed *Deprez's* characteristic curve connecting these qualities will be obtained, the form of which depends on the construction of the machine.

If we now arrange the machine as a series dynamo, by connecting the armature and field magnets in series, then we obtain the characteristic curve

under the condition that the current produced is the same as that which excites the field magnets. The curve A F D when once constructed for any definite speed enables us to find the particular value of the current represented by A E, which corresponds to a given E. M. F. represented by E F.

Deprez's Theory of the Dynamo Machine.—If the electromotive force E and the strength of current C are known, the resistance can be determined by Ohm's law thus from the curve A G C in Fig. 309:

$$E = C \times R, \text{ or } R = \frac{E}{C} = \frac{G\,E}{A\,E} = \tan G\,A\,E.$$

Thus the total resistance is expressed by the tangent of an angle which can be graphically constructed.

In a similar manner by means of these graphic methods all problems relating to dynamo machines may readily be solved. If, for example, we start with a definite resistance and gradually diminish it, the line A G, the inclination of which measures the resistance, will have to be drawn at a gradually diminishing inclination to O X, in the direction A C. On comparing the values of G E for different positions of G, it will be seen that the value of E at first increases rapidly, then more slowly, and finally remains constant.

If we now increase the resistance the line A G approaches the vertical axis, and will cut the curve nearer and nearer the origin A, and at the position A N will be a tangent to the curve at the origin. With this resistance in circuit, represented by this limiting position, the machine will not produce a current at all.

We have previously considered the velocity of rotation to be constant, and the characteristic curve thus obtained is only true for this particular velocity v. In order to obtain a similar curve for a velocity v_1 it is only necessary to multiply the vertical distances E by $\frac{v_1}{v}$. This is based on the assumption, which is only true within small limits, that the values of the E. M. F. are proportional to the velocities. If we know the characteristic curve for a velocity v and require to know the E. M. F. e and strength of current C, for definite resistance R and a velocity v_1 we proceed thus: Let $\frac{v_1}{v} = K$, then $E = K\,e$, and therefore $C = \frac{K\,e}{R}$. C corresponding to the resistance R for the velocity v_1 is thus obtained by determining the strength of current for the resistance $\frac{R}{K}$ in the curve for the velocity v. An E. M. F. e corresponding to this current C for the velocity v_1 has to be multiplied by K to obtain the electromotive force E for v.

A very important problem is the determination of differences of potential between any two parts of the current circuit which are separated from each other by a definite resistance. Let the total resistance be R, and the resistance of the part of the circuit, the difference of potential of which is to be determined, be r.

Draw the lines A M + A L so that the tangent of M A X and the tangent of L A X represent the resistances R and r respectively. Then

$$M K = A K \times \tan M A K = C \times R.$$
$$L K = A K \times \tan L A K = C \times r.$$
$$M L = M K - L K = C \quad (R - r).$$

According to Ohm's law, C $(R - r)$ is the electromotive force between the two points of the circuit, which are separated by the resistance $R - r$, and is the e sought for.

If tangent L A K represents the internal resistance of the machine, and the total resistance be varied, then M L will represent the difference of potential or E. M. F. between the terminals of the machine.

Another important graphic diagram is formed by plotting out the difference of potential between one bar or brush of the current collector, and each of the other bars or brushes.

The Commutator Curves. — In a well-constructed dynamo-electric machine the several parts are traversed by currents which come from the positive brush and traverse the two divisions of the winding, and meet in that piece of the collector which touches the negative brush. Every division or bobbin of the armature adds its electromotive force to that of the preceding one, and therefore strengthens the current traversing it. If, now, the potential between the negative brush and the succeeding sections of the collector be measured, it will be found that it increases regularly in both directions, linearly on the collector, and attains its maximum at the opposite side, where the positive brush is. This can be proved experimentally by the aid of a galvanometer, one pole of which is attached to the negative brush, while a flexible piece of copper is attached to the other pole, and with it the several radial pieces of the collector are touched in succession. If the several observed differences of potential be graphically recorded on a drawing of the periphery of the collector, a diagram like that given in Fig. 310 will be obtained. In this way we can observe the regular growth of the tension from the lowest point of the circle, which point represents the negative brush, up to the maximum of the positive brush. If these graphic values are represented on a straight line, which will be equivalent to imagining the periphery of the collector as unrolled upon a plane, the diagram represented in Fig. 311 will be obtained. This shows that the potential does not increase regularly between the neighbouring segments; if it did, the curves would resolve themselves into two straight lines. In reality, the increase

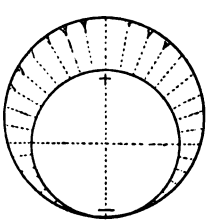


Fig. 310.—Difference of Potentials on a Collector of a Gramme.

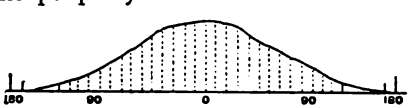


Fig. 311.—Horizontal Arrangement of Potentials.

of potential proceeds most slowly in the neighbourhood of the two brushes, and the rate of increase is greatest at a point about 90° from the brushes. It is there where the bobbins of the armature pass the part of the magnetic field which exerts the greatest inductive action. If the magnetic field was entirely homogeneous, the number of lines of force cut by the bobbins rotating in the field would be proportional to the sine of the angle which the plane of the bobbin makes with the direction ot the magnetic lines of force. This is nearly the case represented in Figs. 310 and 311.

The measurements relating to the division of the E. M. F. at the collector are of great practical interest. They not only show where the brushes should be placed in order to gain the best effect, but enable us to compare the efficiency of the bobbins in various parts of the magnetic field. If the brushes are located at the wrong place, or if the pole-pieces of the field magnets have a wrong shape, the run of the potentials at the collector will be irregular, and maxima and minima will be observed at other points than those where the brushes touch the collector. An actual diagram of the relations of the potentials at the collector of a machine of faulty construction is shown in Fig. 312. It is transferred to a horizontal line in Fig. 313. By these it is to be seen that the division of potential at the collector is irregular, and so much so that one portion of the collector has a greater positive potential than the positive brush, and another portion a greater negative potential than the negative brush. Therefore one portion of the current produced by the machine is destroyed by another portion; and it would be possible to lead off another current by another pair of brushes placed so as to touch at these points of maximum and minimum potential.

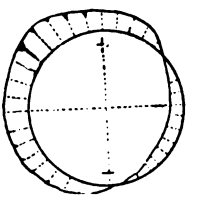


Fig. 312.—Potentials with a Collector of a badly-arranged Dynamo.

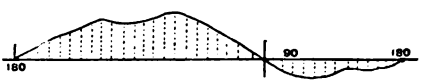


Fig. 313.—The same horizontally.

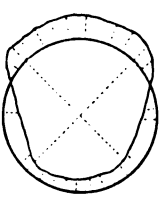


Fig. 314.—Potential Diagram for the Brush Commutator.

All machines with collectors and simple magnetic fields give curves like the one in Fig. 310. The Brush machine, however, which has a simple magnetic field, but a commutator instead of a collector, shows an entirely different disposition of the potential. Over one-eighth of the circumference on each side of the points of contact of the positive brush, there is no perceptible difference of tension; all points have the same tension, which is that of the brush itself. The same is the case in the neighbourhood of the negative brush, where the

tension has the constant value due to this brush. Between these there are points where the tension becomes smaller, and passing through zero changes its signs. This is shown in diagram Fig. 314.

Comparison of the Series and Shunt Machines.—When the resistance of the external circuit is considerable, the strength of the current, according to Ohm's law, will be weak; and as the machine has to provide the electros with current, the feeble current will only give a feeble intensity to the magnetic field. We may say, therefore, that the current suffers two reductions for every increase in the resistance; one because of the resistance, the other because the first fall diminishes the intensity of the field. If the outer resistance be infinitely large, *i.e.* the outer circuit broken, the intensity of the magnetic field will be zero, neglecting the residual magnetism. The dynamo-electric machine then will give no current, even when the armature is constantly rotating. When, on the contrary, the resistance of the outer circuit is only very small, as, for example, when it is that of a short thick copper wire, the current will attain considerable strength. In the third formula above,

$$C = \frac{4n\,A\,M}{R},$$

and this shows that C is diminished, both by increasing R and by diminishing M. C then, in a dynamo-electric machine, is very sensitive to the changes of resistance in the outer circuit.

The above conditions hold good for dynamo-electric machines in which the armature, the magnets, and the outer circuit are joined in series. Such an arrangement is shown (Fig. 315) for an Edison machine. This arrangement has certain features which may for certain purposes be very troublesome. If, for instance, the machine has to supply arc lamps with current, the carbons of the lamps are consumed, and the gap produced makes the resistance in the outer circuit larger; when, now, the mechanism for adjusting the carbons does not work very accurately, that is, does not move the carbons towards each other at a rate proportionate to their consumption, the greater resistance will remain for a longer or shorter period, and thus cause a weakening of the current. This weakening of the current appears just at a time when an increase of current would be wanted, to overcome the greater resistance of the outer circuit.

Various methods have been tried to avoid this dependency of current upon the resistance. One of these is to give double coils to the armatures, using the currents induced in one group for the field magnets only; and the currents induced in the other group in the outer circuit. Sometimes a certain number of bobbins of the armature are connected with the electro-magnet coils, whilst the currents induced in the remaining bobbins are conducted into the outer circuit.

Three different kinds of machines agree in principle with those magneto-electric machines, the magnets of which are induced by separate sources of electricity. The shunt arrangement is shown in Fig. 316; the currents divide at *b*, one branch flows through the coils of the magnets, the other branch flows

through the outer circuit to b_1, and the two branches unite again and return to the armature. We know that in divided conductors the strength of the current in the different branches is inversely proportional to the resistance in these branches. In this arrangement the current in the outer circuit will depend upon the proportional resistance of the two circuits. When the resistance in the outer circuit is increased, a larger portion of the current will flow into the coils of the magnets; when the resistance decreases, the current in the coils of the magnets will also decrease. If, again, we insert a lamp in the outer circuit,

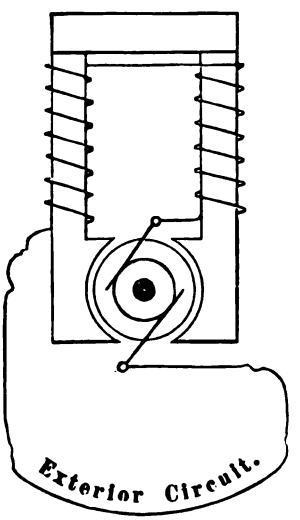


Fig. 315.—A Series Dynamo.

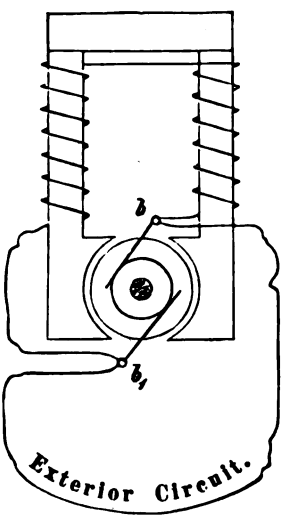


Fig. 316.—A Shunt Dynamo.

the increased resistance of this lamp will also increase the current in the magnets. Putting the field magnets in shunt, therefore, effects a kind of current regulation, corresponding to the wants in the outer circuit. As in the case of the series generator, we may express these conditions in an equation.

Shunt Dynamo Machines.—

Let R = the resistance of the external main circuit.
„ C = the current in the same.
„ r_a = the resistance of the armature.
„ C_a = the current in the same.
„ r_s = the resistance of the shunt.
„ C_s = the current of the same.
„ E = the total E. M. F. produced.
„ e = the E. M. F. between the terminals $b\,b'$ of the external circuit.

The main current is that of the armature, and it is this that is divided into two parts, hence $c_a = C + c_s$.

The joint resistance of external circuit and magnetic coils is $\frac{R r_s}{R + r_s}$.

Hence the total resistance of the circuit is $r_a + \frac{R r_s}{R + r_s}$, and Ohm's law therefore gives us the three following equations:

$$\text{In the whole circuit } E = \left(r_a + \left(\frac{R r_s}{R + r_s}\right)\right) c_a.$$

$$\left.\begin{array}{l}\text{In the outer circuit} \quad e = C R \\ \text{In the magnetic coils } e = c_s r_s\end{array}\right\} \therefore C + c_s \text{ or } c_a = \frac{e (r_s + R)}{r_s R}.$$

$$\text{Therefore } E = e\left(\frac{r_a}{R} + \frac{r_a}{r_s} + 1\right)$$

On the Value of R that gives a Maximum Efficiency.—

I. Work done per second in the outer circuit is Ce or C^2R.

II. The energy wasted in heating in the shunt is $c_s e$ or $c_s^2 R$.

III. Similarly the energy wasted in heating in the armature is $c_a^2 r_a$.

Hence the electrical efficiency or

$$\frac{\text{useful work}}{\text{total work}} = \frac{\text{I.}}{\text{I.} + \text{II.} + \text{III.}} = \frac{C^2 R}{C^2 R + c_s^2 r_s + c_a^2 r_a}.$$

From the equations $e = C R$, and $e = c_s r_s$ we have $c_s = \frac{C R}{r_s}$.

From the equation $C + c_s = c_a$ we have

$$c_a = C + \frac{C R}{r_s} = \frac{r_s + R}{r_s} C.$$

Substituting the above values for c_s and c_a, and remarking that then C^2 cancels, we obtain

$$\frac{\text{useful work}}{\text{total work}} = \frac{R}{R + \frac{R^2}{r_s} + \frac{r_a (r_s + R)^2}{r_s^2}} = \frac{1}{1 + \frac{R}{r_s} + \frac{r_a (r_s + R)^2}{r_s^2 R}}.$$

Now this quantity will be a maximum for that value of R that will make the denominator the least possible. This denominator may be written thus:

$$1 + \frac{R r_s}{r_s^2} + \frac{R r_a}{r_s^2} + \frac{r_a}{R} + 2\frac{r_a}{r_s};$$

or by writing r for $r_a + r_s$, and adding and subtracting $\frac{2\sqrt{r r_a}}{r_s}$, the denominator in question becomes

$$1 + 2\frac{r_a}{r_s} + R\left(\frac{r}{r_s^2} - \frac{2\sqrt{r}\sqrt{r_a}}{r_s R} + \frac{r_a}{R^2}\right) + \frac{2\sqrt{r r_a}}{r_s}.$$

Now the part of this expression that changes when R changes is

$$R\left(\frac{\sqrt{r}}{r_s}-\frac{\sqrt{r_a}}{R}\right)^2.$$

Whatever R may be, this portion of the expression is positive (for every square quantity is always positive), and therefore the above denominator is the least possible when this quantity is zero, that is to say, when

$$\frac{\sqrt{r}}{r_s}=\frac{\sqrt{r_a}}{R},$$

$$\text{or } R = r_s\sqrt{\frac{r_a}{r}}.$$

This gives for the efficiency

$$\frac{1}{1+2\frac{\sqrt{r_a}(\sqrt{r_a}+\sqrt{r})}{r_s}}.$$

If r_a be very small compared with r_s, then r is but little more than r_s, and in this particular case the value of R is nearly equal to the geometrical mean of r_s and r_a, for

$$R = r_s\sqrt{\frac{r_a}{r_s}} = \sqrt{r_s\, r_a}.$$

Variation of Resistance according to the Purpose served.—The inner resistance of a machine, *i.e.* the resistance of the wire of the armature and the electro-magnets, must be determined according to the purpose for which the machine is going to be used. Upon it depends the intensity of the induced current. When the inner resistance is considerable, currents of high potential are obtained, and the currents in the outer circuit will have a high resistance also, and may be employed, for instance, for feeding a number of lamps put in series. For a short conductor and a working conductor of small resistance, machines of a small inner resistance are used. A certain amount of resistance, however, is necessary in every machine, as without it generation of current would be impossible, because by the transmission of energy, be it in the voltaic arc or decomposition cell or secondary machine, a counter current is created. In alternate current machines, which can only be used for lighting purposes, this opposition current aids the machine current instead of weakening it. Yet for nearly all purposes continuous current generators are preferable to alternate current machines. In constructing machines useless resistances ought to be avoided as much as possible, as, for instance, unproductive wires at the ends of the Siemens drum; these ought to be reduced to a minimum.

Effects of Heating.—Every conductor having electricity passing through it is heated, and is heated the more (under otherwise equal conditions) the

greater the resistance of the conductor. But the conversion of electricity into heat within the machine means loss of energy, as the machine is intended to return the equivalent in electricity and not in heat. Heating of the machine is further objectionable for the reason that it injures the insulation. The frequent change of polarities is another cause of the production of heat; we know even the softest iron does not lose its magnetism entirely as soon as the inducing magnet or current ceases to influence it. There is a coercive force resisting the change. As the machine rotates with considerable velocity, the respective pieces of iron will still have traces of the former kind of magnetism when they become oppositely magnetised; in this manner the iron particles are in constant motion. Hence, all the energy is not converted into magnetism, for some of it becomes heat. The heating of the magnet again reacts, by causing the weakening of the magnet also, and therefore a diminution of E. M. F. and of current. It becomes desirable, therefore, to prevent this heating of the magnet as much as possible.

The generation of heat in Gramme's ring and Siemens' cylinder is considerably reduced by the gradual magnetisation. For every complete revolution of the armature a change of polarity takes place twice; yet in these machines the time allowed for the iron to change its polarity is $\frac{1}{1000}$ minute, when the armature has 1,000 revolutions per minute. The generation of heat owing to the rapid change of polarity has been reduced, first by facilitating the rapid demagnetisation of the iron, and secondly, by giving the iron a longer interval of time to lose one kind of magnetism before the opposite kind is induced. The change of poles is facilitated by making the armature not of one massive piece, but of several pieces, or even of wires or plates. Time for the change of poles is obtained by having the spaces between the magnetic fields not too small. In most machines of recent make the former plan is used; the latter we see employed in the machines by Schuckert. Heating in consequence of the rapid and frequent change of polarity is entirely avoided in such machines as have no iron in the armature, as, for instance, the new coil machines of Siemens, and in the uni-polar machines, in which no change of poles and no change in the direction of current in the armature takes place, because the latter always moves in one and the same magnetic field.

A further source of heat are the Foucault's or eddy currents, which always arise when metals move in magnetic fields. Heat produced in this way increases with the size of the machine. This inconvenience may be remedied by means of the division of the metallic material, which will to a great extent obviate the production of these currents.

Generation of heat in electrical machines causes loss of energy during conversion of mechanical work into electricity. This, however, is not the only source of loss. The nature of the process which takes place in electric machines is very complicated, and as yet not fully understood. The powerful currents produced by the machine must, for instance, affect the wires through

which they flow, as well as the other metallic portions of the machine, and self- and secondary induction occur to disturb the working. The efficiency of the machine will thus no doubt be increased one way, but also diminished in another way. The currents, for instance, which surround the iron cores of the armature will weaken the magnetism of the iron cores, and this is the chief cause of the limit with which the increase of a current meets so rapidly when we use a dynamo-electrical machine. These obstacles, due to secondary induction, increase with the number of turns in the coil, and with the speed, because by means of these the strength of the current, which calls the secondary induction into existence, is also increased. Although the strength of the current increases far more rapidly than the secondary induction produced by it, yet the latter causes a loss of energy which is far more considerable in alternating current machines, because the continued change of the current produces currents at make and break which will increase the formation of sparks and bring about other hindrances.

Review of the Relation between the Practical Units of Electricity, Work, and Heat.—Further sources of loss are, of course, the friction of the parts of the machine, and of the air particles which oppose the rotating portions of the machine, etc. etc. To judge, therefore, the efficiency of a machine, we must know what percentage of electrical energy it will return. In order, then, to calculate the electrical energy from the mechanical work expended, we require certain units. The units used, until a short time back, were more or less arbitrary. At a meeting of electricians, held in Paris in 1881, an absolute system has been agreed upon, the basis of which is the centimetre, gramme, second (C. G. S. units). The relation of these units to one another is explained in the Appendix to Part I. on page 222.

It will be convenient here, however, to notice several additional facts respecting the various systems of derived practical units.

In the metre-kilogramme-second system, with the weight of a kilogramme as the unit of force, the unit of mass will be the kilogramme divided by the acceleration due to gravity, or 9·81, the acceleration being 9·81 metres per second in a second. The unit of work will then be the metre-kilogramme, which is equal to 7·233 foot-pounds, and the rate of working the second-metre-kilogramme. 75 second-metre-kilogrammes are a French "force de cheval" equal to 7,360,000,000 ergs per second. In the English second-foot-pound system, if the weight of a pound be the unit of force, the unit of mass is one pound divided by 32·2. The unit of work is then the foot-pound, and unit rate of working a horse-power, which is 550 foot-pounds per second, or 7,460,000,000 ergs per second.

The practical units of electricity already mentioned are the *coulomb* for quantity, *ampere* for strength of current equal to the flow of a coulomb per second, and the *volt* for E. M. F. When a quantity of electricity measured in coulombs falls from a higher to a lower potential, the work which is set free is represented by the number of coulombs, by the difference in volts. Hence,

the rate of working per second is given by multiplying the number of amperes by the number of volts.

$$1 \text{ volt} \times 1 \text{ ampere} = 1 \text{ watt.}$$

Hence, a watt is the rate at which work is done by a current of one ampere working through one volt; it is $\frac{1}{746}$ (or ·00134) of a horse-power, or ·7373 foot-pounds per second. It is $\frac{1}{736}$ (or ·00136) of a cheval-vapeur, and ·109 metre-kilogrammes per second.

The heat which will raise a gramme of water 1° Centigrade is called a *calorie.* The number of calories developed in a circuit is equal to the square of the current in amperes multiplied by the resistance of the circuit in ohms, multiplied by the time in seconds, and divided by Joule's equivalent.

Hence, a current of one ampere, in working through one volt, develops in the circuit an amount of energy (called a joule), the heating effect of which is equivalent to ·2406 calorie. (Note that $\frac{1}{\cdot 2406} = 4{\cdot}2$). Hence,

$$C^2 \text{ (amperes) } R \text{ (ohms) } t \text{ (seconds)} \times {\cdot}2406 = H \text{ (calories),}$$

or in ampere-volt-ohm seconds,

$$C^2 R t = C E t = H \text{ (joules).}$$

We obtain the electrical energy of current in kilogramme-metres when we divide the product of the quantity in coulombs and the E. M. F. in volts by 9·81.

$$\frac{\text{Number of coulombs} \times \text{potential in volts}}{9{\cdot}81} = \text{kilogramme-metres.}$$

The strength of a current we have measured by the number of coulombs flowing per second. One ampere per second is a coulomb. (*See* page 222.) Hence the work done per second,

$$\frac{\text{Strength of current in ampères} \times \text{E. M. F. in volts}}{9{\cdot}81} = \text{energy in kilogramme-metres}$$

If the effect is to be given in horse-power, we have to divide by 736 the measure in cheval-vapeur.

$$\frac{\text{Strength of C in amperes} \times \text{E. M. F. in volts}}{736} = \text{energy in cheval-vapeur.}$$

Dynamometers.—To calculate the efficiency of any machine we require to know the amount of work transmitted by the engine or motor to the machine. This is determined experimentally by a dynamometer; such a dynamometer is represented in Fig. 317. Prony's break *c* is a disc of cast-iron of similar shape to the rubbers of an electrical machine. It is held by two wooden clasps *a a*. The lever *b* is fastened to the upper wooden piece, and supports a scale-pan at P for weights. The two wooden pieces *a a* are screwed together at *s s*. In order

to take measurements with Prony's break the disc *c* is fastened to the shaft, the effect of which is to be determined; the screws are adjusted so that the wooden blocks lie close to the disc. The machine is then made to rotate with a certain velocity (that velocity, of course, the effect of which is to be determined). If no weights were placed at P, the break would be turned round with the shaft; but weights are placed at P so as to keep the beam *b* horizontal, whilst the shaft makes the number of revolutions required. Friction, which consumes the mechanical work transmitted to the shaft, is measured by the force which tends to press the scale-pan down at P. This force is in equilibrium at *c* with the friction. As the weight P, the length L of the lever, the radius of the roller *c*, and the revolutions per minute of the shaft are known, the effect (*i.e.* the work done) can easily be calculated from these factors in horse-power.

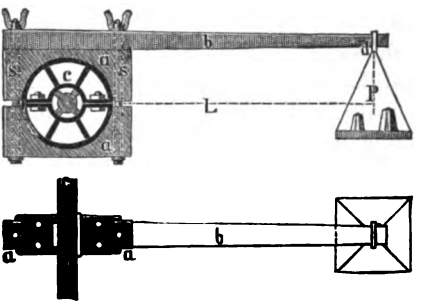


Fig. 317.—Prony's Dynamometer.

The apparatus by Hefner von Alteneck is often used. It measures the work transmitted by means of a driving belt, from the difference between the tension of the backward and forward running portion of the belt. The

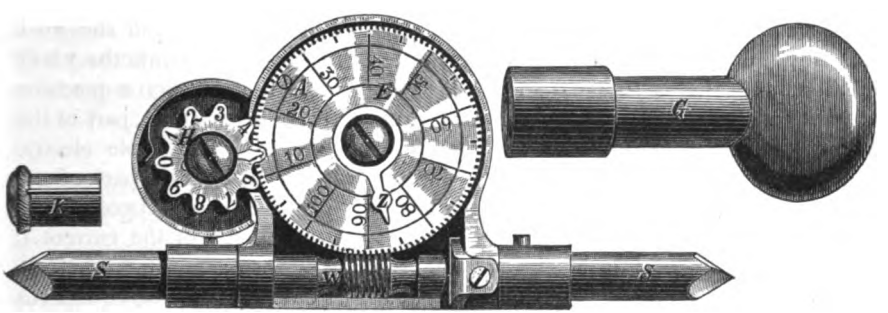


Fig. 318.—Lang's Speed Counter.

force thus obtained is calculated in kilos. and has to be multiplied by the velocity of the shaft (given in metres) to obtain kilogramme-metres. To determine the number of revolutions, speed counters are used. Fig. 318 represents such an apparatus, constructed by W. Lang, Brooklyn. It consists of the movable spindle s s, the ends of which are edged, as shown in the figure. The spindle has at the middle an endless screw w, which catches the teeth of the disc E; the disc having 100 teeth cut into it, the spindle will make 100 revolutions for every revolution of the disc. The scale on the disc gives 100

revolutions; the fixed pointer Z points out the number. The disc E is furnished at A with a projecting piece of metal, which strikes the disc H once for every complete revolution of E, and moves the disc H one tooth farther on. The wheel H will therefore make one revolution when the disc E has to make 100 and the spindle 1,000 revolutions. By means of the handle G the spindle is held against the centre of the shaft (which end depends on whether the shaft turns to the right or to the left) in such a manner that both axes fall in one line, and the spindle makes as many revolutions as the shaft.

After a certain period, say one minute, the instrument is again removed, and the number of rotations read off from the two discs. The two discs, of course, will point to the zero of the scale before the experiment commences; a shield K protects the point.

The Efficiency of Electromotors.—Connect in series a battery, a galvanometer, and a small electromotor. Hold the electromotor at rest and observe the deflection of the galvanometer. Let the electromotor work, and again observe the deflection. The deflection is less in the second case than the first, showing that the more rapidly the motor revolves, the greater is the falling off in the current. How is this? The reason is, that when an electromotor is working it produces a back electromotive force tending to diminish the current.

Let us consider now the efficiency of a motor worked by a current from a battery or other generator. We shall show that the electric energy of the current depends upon the ratio between the counter electromotive force and the electromotive force of the current which feeds the magnet. We are familiar in ordinary mechanics, with the fact that no machine ever yields all the work that is given to it, and similarly no motor ever turns into useful work the whole of the current that is supplied to it. It is impossible to construct a machine without resistance, and we have seen that wherever there is resistance, part of the energy of the current is wasted in heat. Let W stand for the whole electric energy developed per second by the current, and let w be that part of the energy which the motor pays out as useful work. The difference between these quantities is the equivalent of $C^2 R$, or that part of the energy of the current C that is wasted in useless heating of the parts of the circuit where there is resistance. If H be the measure of this heat, and J Joule's mechanical equivalent of a unit of heat, then

$$W - w = H J = C^2 R$$
$$\therefore \quad w = W - C^2 R.$$

But if E be the E. M. F. of the terminals of the motor when at rest, $W = E C$,

$$\text{and } C = \frac{E - e}{R} \quad \therefore W = E \frac{E - e}{R}$$
$$\therefore w = E \frac{E - e}{R} - \frac{(E - e)^2}{R}$$
$$= \frac{E e - e^2}{R}.$$

$$\text{Hence the efficiency } \frac{w}{W} = \frac{Ee - e^2}{R} \div \frac{E(E-e)}{R}$$

$$= \frac{e}{E} = \frac{\text{back E. M. F.}}{\text{E. M. F. produced by battery}}.$$

Since $W = EC$, therefore $w = eC$. Again, if S be the current that would flow if the motor were still, C being the current when the motor works, we have

$$S = \frac{E}{R} \text{ or } E = SR,$$

$$C = \frac{E-e}{R} \text{ or } e = E - CR = SR - CR.$$

$$\text{Hence the efficiency or } \frac{e}{E} = \frac{SR - CR}{SR} = \frac{S-C}{S},$$

or the fall of strength of current divided by the original current.

The Maximum Efficiency of a Motor.—Let us now go back to the equation

$$w = EC - C^2R,$$

and ask for what value of C this w will be a maximum.

By adding and subtracting $\frac{E^2}{4R}$, we may write the equation thus,

$$w = \frac{E^2}{4R} - R\left(\frac{E}{2R} - C\right)^2.$$

The last term, being a square, is always positive, whatever C may be; hence, w will be greatest when the term to be subtracted is nought.

$$\text{Then } C = \frac{E}{2R}.$$

That is to say, *the mechanical work given out by the motor is a maximum when the motor is geared to run at such a speed that the strength of current is half that of the current that would flow if the motor were still.* This law is called Jacobi's law of maximum activity. When the motor works so as to reduce the current to half,

$$\text{since } C = \frac{E-e}{R}$$

$$\text{and also } C = \frac{E}{2R}$$

$$\therefore E - e = \tfrac{1}{2}E$$

$$\text{and } \frac{e}{E} = \tfrac{1}{2}.$$

But we have proved that this is equal to the efficiency; hence, when the motor does its maximum of work per second the efficiency is 50 per cent.

Distinction between the most Economical and the most Efficient Rate.—If the E. M. F. of battery be E volts, and the counter

E. M. F. of electromotor be e volts, C being the current, then, as we have seen, we have the following simple relations:

(1) The energy put forth by the battery = C E.

(2) The energy given out by the motor = C e.

(3) The efficiency of the motor = $\frac{e}{E}$.

(4) The current C = $\frac{E-e}{R}$.

(5) The work w per sec. = E C$-$C^2 R.

The second of these equations shows that the maximum work that can be given out by this electromotor per second is equal to the product of the current into this back electromotive force. There are two ways, therefore, of altering the work given out by the electromotor per second. We may either increase the current, or increase this back electromotive force. Let us consider the first case: We will double the current, and at the same time keep the electromotive force of the generator the same. To do this we shall have to let the electromotor run at such a diminished speed that the difference between the electromotive force of the generator and the back electromotive force of the electromotor is double what it was before. Although, therefore, we have doubled the current and the energy furnished by the generator, we have not doubled the energy given out by the motor. Where is the additional energy lost? The answer is obvious, since as the waste of power in the production of heat in the wires is proportional to the square of the current, four times as much power will be wasted as in the previous case. Consequently, increasing the current is a ruinous way of increasing the transference of energy.

Now take the other case: Let us double the electromotive force of the generator, and run the motor at such an increased speed that the current remains constant: to do this we must more than double the back electromotive force of the motor. For as E becomes 2 E, e must become (E + e), that the difference may be unaltered. The energy now furnished by the motor will be double what it was before, the energy given out by the motor more than double what it was before, and the energy wasted in heat will be the same as before.

Consequently we conclude that the most efficient way to transfer energy electrically is to use a generator producing a high electromotive force, and a motor producing a return high electromotive force.

When an electromotor is worked by a given galvanic battery, calculations lead us to the result that if we wish to produce the work *most economically* we must, by diminishing the load on the motor, allow its speed to increase until the reverse current it produces is only a little smaller than that sent by the battery. When this is the case, the current circulating through the arrangement is very small, and the efficiency of the engine, or the ratio of the work it produces in a given time to the maximum work it could produce from the same consumption

of material, is nearly unity. If, on the other hand, we desire a given battery to cause the motor to do work *most quickly*, independently of the consumption of material, then calculation tells us that we ought to put such a load on the motor that its speed will send a reverse current equal to something like half the strength of current the battery could send through the motor when at rest. The efficiency is then about half; that is, half the energy is wasted in heat.

The difference between these two considerations of maximum values, namely, how to obtain work *most quickly*, or how to transmit work *most economically*, must carefully be borne in mind in deciding what speed should be given to a motor.

Results of Experience bearing on the Construction of Machines.—There are a few rules with regard to the form and dimensions of parts which are based on experience. For the different purposes the requirements differ. The section of the wire, for instance, will depend upon what strength is required for the current. Flat electro-magnets are preferable to round ones, because the former for the same surface have a smaller cross section, and consequently less resistance. When large masses of iron are to be magnetised—as, for instance, the shoes in Edison machines—it is better to use several magnets. The coils and bobbins are to be so proportioned that in the magnets not more than 20 volts difference of potential exists between two adjacent groups. The magnets ought to be arranged so that as little space as possible remains to be filled by the armature, and should satisfy the following conditions: The poles of the magnets should be arranged so that there are few useless lines of force; that is to say, so that as few lines of force as possible pass from pole to pole without cutting the wires intended for induction. The iron core of the armature must approach the shoes of the magnet as near as possible. The wires of the rotating bobbins must be arranged so as to cut the lines of force, as wire which does not do so is not only useless, but increases the dead resistance. It has already been mentioned that, in order to prevent Foucault's currents, the iron core should be made up of separate parts (wires, discs, etc.). Great care ought to be taken that insulation is perfect in all parts of the machine. Insulation ought to be sufficiently strong to bear one and a half times the potential difference which is produced when either clamp is placed to earth (Uppenborn). Parts of a machine which are most subject to wear are the bearings of the shaft, the commutator, and the rotating portions (armature or field magnets). The bearings ought to be wide, properly fastened, easily to be reached, and supplied with lubricators. The commutator is corroded, worn, and damaged, by generation of sparks and leakage of lubricants. The generation of sparks occurs, of course, with currents which have a high potential (or tension) more than with currents of low potential. Other things being equal, the means of diminishing the generation of sparks have been considered in the description of the several machines. The auxiliary brushes by Edison, alternating coiling of the armature wires by Weston, etc., are for this purpose. When the oil coming from the lubricator reaches the copper segments of the commutator, the electric sparks effect decomposition,

the products from which help to destroy the commutator. Again, the oil itself may become mixed with dust, particles of metal, etc., which will injure the insulation between the sectors. Care ought to be taken, then, that the oil from the lubricator cannot get to the commutator. The commutator being that part of the machine soonest worn out, those machines deserve preference in which it is easy to replace an impaired instrument. Better still are those machines that need no complicated commutator, like the machines by Ferraris.

The rotating coils may become useless by having their insulation spoiled through heating or other causes, or their wires may be broken. It is always a recommendation for a machine when it is so constructed as to allow of an easy and quick replacement of the injured parts—as, for instance, in the machines by Schuckert. In machines where the coils are separated from each other, exchange is easiest brought about—as, for instance, in the new machines by Siemens. If these points are not considered in the construction of a machine, it becomes necessary to have an extra or a reserve armature with the machine, whilst in the machines mentioned duplicates are required only for such parts as are likely to suffer. Schuckert's arrangement of the armature (placed upon the ground frame open at one end) has, besides, this advantage, that the loosening of a few screws is sufficient to allow the removal of the armature, and to replace the injured part by a new one.

The advantages and disadvantages of currents of high and low potentials are intimately connected with the different purposes the electricity has to serve, and will therefore be considered later on.

Theory of Large Dynamos.—Finally we have to consider whether for very powerful currents it would be better to construct generators of enormous dimensions, or to combine several machines to furnish the desired current. At present we cannot very well answer this question. Professor Perry and Mr. J. E. H. Gordon* think machines of large dimensions ought to be constructed,

* The following is the summary of Mr. Gordon's arguments in favour of large machines :—

"It is found experimentally, and can be proved mathematically, that if a coil of wire forms part of a circuit, and an alternating E. M. F. sends a current through it, the current will be much less than it would have been had the same resistance been interposed in the form of a straight wire.

"Further, the proportional diminution becomes greater as the current is increased by the reduction of the resistance; and finally, for a given E. M. F., a given rate of alternation, and a coil of given shape, a limit is reached beyond which even reducing the resistance to zero does not increase the current.

"This diminution, however, does not, to the best of my belief, waste energy or diminish the efficiency of the machine; it only diminishes its output. Thus self-induction increases the size of a machine required to feed a certain number of lamps, but it does not perceptibly increase the horse power required to drive the machine with that number of lamps on it.

"The effect of self-induction increases as the current increases, and therefore short-circuiting a coil of an alternating machine does not indefinitely increase the current in that coil, and seldom increases it enough to injure the insulation.

"The true secret of successful regulation is to have very large dynamos, because then, as we have said before, the maximum number of lamps that can be turned out at one time is a very small percentage of the whole, and when there are a great number of lamps on one machine, the cost per lamp of regulating, either by hand or by an elaborate mechanical contrivance, is very trifling."

whilst others, and especially German electricians, think the size of machines ought not to be pushed too far, and would rather have several machines coupled together in form of batteries.

The connection of several machines in one circuit requires that certain conditions shall be taken into consideration. Dynamo-electric machines are like other electrical generators with two poles, and may be joined either in series or parallel.

With all electric currents that do work polarisation takes place; the maximum efficiency will therefore correspond with a certain proportion between the E. M. F. of the machine and the counter E. M. F. of the polarisation. Experiments by Ferrini confirm the theory which we have already developed, and show that the maximum efficiency takes place when the proportion is = 2 : 1; that is, $\frac{\text{E. M. F. of polarisation}}{\text{E. M. F. of machine}} = \frac{1}{2}$, or, when the E. M. F. of the machine = 2 × the back E. M. F. of polarisation. Numerous experiments made by the Austrian engineer, M. Burstyn, with Gramme machines of different types, also confirm this theory.

Combinations of Machines.—These experiments showed that the Gramme machines are constructed so as to answer the demands of economy, and that if connected with each other they may be joined for quantity, but not for tension. The mode of coupling the machines is a matter of great importance. Gramme, according to Burstyn, was the first to show how this could be done with advantage. In Fig. 319 two machines I and II are put in divided circuit. I_1 and I_2 are the armatures, C_1 and C_2 the collectors, with their brushes B_1 and B_2, from which wires lead to the binding screws P_1 N_1 and P_2 N_2. E_1 and E_2 are the wire coils of the electro-magnets, and L represents a lamp inserted in the circuit of both machines. At *a* the currents of both machines meet, and pass through the conductor *a c* to the lamp, which they leave again at *d*. The current is again divided at *b*, one portion flowing back to one machine, the other portion back to the other machine. The direction of current will be as follows:

$$\left.\begin{matrix} + \; B_1 \; E_1 \; P_1 \\ + \; B_2 \; E_2 \; P_2 \end{matrix}\right\rangle \; a\,c, \text{ lamp, } d\,l \; \left\langle \begin{matrix} N_1 \; B_1 \; - \\ N_2 \; B_2 \; - \end{matrix}\right.,$$

through the lamp, therefore, a current flows, which is the sum of two currents. If the E. M. F. in both machines be equal, no matter how large the resistance in the lamp may become, the currents of both machines will always flow through the lamp circuit in the same way. When contact is entirely broken at L, the E. M. F. produced by the two generators being exactly equal, the circuit of the machine will remain current-less even when the armatures are kept in motion.

If, however, the E. M. F.s of the two machines are not equal to each other, and the resistance in the lamp has been increased beyond a certain limit, a portion of the current of the stronger machine will flow at *a* into the weaker machine, and will flow through its coils in an opposite direction to the direction of the

current generated by it; this will happen, for instance, when the lamp goes out. If now the two machines are not stopped, the machine that has the smaller E. M. F. will have a current flowing in an opposite direction to that which it generates, equal to the difference of the E. M. F.s by the resistance in the total circuit.

In consequence of this differential current, the electro-magnets of the weaker machine become re-polarised, and the current induced in that machine will be reversed, *i.e.* it will have the same direction as the current in the other machine. A current now will flow through the conductors which corresponds to the sum of the E. M. F.s of both machines, and the machines are now in series. If the machines are not stopped now, they will become heated, as they are short-circuited, and the strength of the current will have been increased enormously. The lamp circuit becomes a branch circuit, which receives only

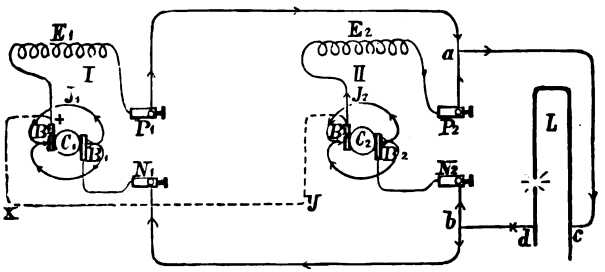


Fig. 319.—Combinations of Machines.

that portion of the total current which is obtained according to the law that it is divided in inverse proportion to the resistances in the two circuits. To obtain the normal lighting effect the weaker machine would have to be reversed, in the sense of the altered polarity.

As two machines, producing exactly equal E. M. F.s, are difficult if not impossible to construct, disturbances of greater or less intensity will take place whenever two machines are joined for quantity in the same circuit. Gramme, however, has overcome this difficulty in a simple manner. All the coils of the electros of the machines which are to be joined for quantity are connected with a brush in electric communication by a short wire with a pole screw, whilst a second brush is connected by means of a short wire with a second pole screw. If two such machines are to be coupled in one circuit, the brushes which are in connection with the coils of the electros are joined, as shown in Fig. 319, by the line $x\ y$. If now the current in machine I become so powerful as to flow over into machine II, the current will be divided into B_1 and B_2 in the inverse proportion to the resistances in the divided circuits E_1 E_2 and $x\ y$; but the resistance of the coils of the magnets being far greater than that of $x\ y$, the first branch will have only a very weak current flowing through it; and even under the most

unfavourable conditions this weak current would never be able to reverse the polarity of the magnets. The opposing E. M. F.s meet each other in the wire $x\,y$, which is therefore currentless when the E. M. F.s of the two machines are equal to each other.

An analogous case in hydraulics may serve to make this action plainer. Imagine the electrical differences of potential represented by the pressure upon liquids and the circuit formed by corresponding pipes, as shown in Fig. 320. As long as the pressures in I and II are equal, liquid will flow from both vessels through L, with a velocity depending on the resistance in the tubes. No matter how great the resistance in L may become, fluid will never flow from I to II, or *vice versâ*, through the tubes E_1 and E_2, provided, of course, the resistances in E_1 and E_2 are not very different from each other When no fluid passes through pipe L, all motion in the whole system ceases of course.

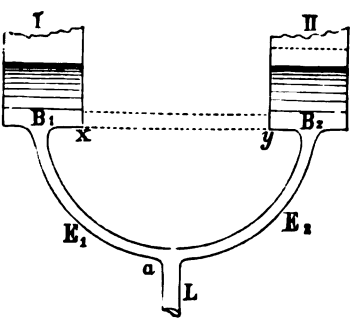


Fig. 320.

If now the pressure in II be greater than in I, and L offers only slight resistance, liquid will flow to L from both vessels, of course with differing velocity; suppose now the resistance in L to become so great as to allow no time for the balancing of the two different pressures, fluid from II must flow to I through E_1. This will take place especially when L allows no fluid to pass at all, *i.e.* when contact in the circuit of the lamp is broken. Equilibrium will be restored by means of E_2 and E_1, and fluid will flow through E_1 in a direction opposite to the pressure in I with a velocity corresponding to the difference of pressure in the two vessels. Repolarisation of machine I would be analogous to alteration of the negative pressure in vessel I, so as to make it equal to the pressure in II. In this case, when L is closed, fluid from I to II would flow through E_2 and E_1. If, however, the two vessels are further connected by means of the wide tube $x\,y$, equilibrium will be restored through this way, and consequently no fluid will flow through E_2 and E_1 to reach either the one or the other vessel.

For want of attention to these details, very unpleasant results occurred at the Edison central station in New York, which Edison himself describes in the following manner: "When two dynamos for the first time were to supply current for about 2,000 lamps, it was found impossible to obtain a uniform speed; whenever one machine made fewer revolutions than the other, the total current went into the more slowly rotating machine, and became thus a kind of electromotor; at the first trial this phenomenon was very startling, and might have easily led to sad consequences. When the second generator was set going, first one machine and then the other machine gave sparks resembling lightning, and one machine drove the other by turns. One of the engineers present cut off

the steam from the motor, and got the machine rotated with the same speed as before. Pale as death, he rushed up to me and asked what was to be done. In the next minute, about eight pounds of copper were melted by the current, and partly volatilised. If all the six projected machines had been used, I don't know what might have happened. However, I soon found out that the unequal speed with which the machines rotated was the cause, and I therefore connected the regulators of all the machines with each other, so as to make the same number of revolutions per second. This alteration, however, required at least one month, and as many of our customers no longer burnt gas, we had to do the best we could with a most serious difficulty. The arrangements made answered very well, and all these difficulties are now overcome."

REGULATION AND DISTRIBUTION OF THE CURRENT.

General Explanation.—Before the current produced by the generator can be used to do the required work, it is necessary to see to its regulation and distribution. The due regulation of the current is of as much importance as the adoption of suitable generators and receivers, *i.e.* the apparatus which produces, receives, and consumes the current, such as lamps, motors, or decomposition cells.

To work with unregulated currents is far from economical, and often causes considerable loss, as may be shown by the following example: Suppose the currents of a machine to have a strength corresponding to the number of lamps which they are supposed to feed. Now suppose that all of a sudden, either by chance or purpose, a number of lamps are put out, at once the resistance in the circuit is considerably diminished. The current being inversely proportional to the resistance, it follows that the decrease of resistance causes increase of current, which will not only alter the remaining lamps, but might injure the insulation of the machine, or melt off portions of metal. To prevent cases like this occurring, the generator may be constructed so as to allow to pass only currents of such strength as are wanted, or regulators constructed for the purpose may be used. Finally, the receivers, *i.e.* the lamps, may be so arranged as to allow only the required current to pass. The fluctuations of current are especially unpleasant in machines where the dynamo-electric principle is thoroughly adopted, *i.e.* where the coils of armatures and coils of magnets together form only one circuit. Every increase of resistance in the circuit here will cause diminution of current as a matter of course; in the dynamo-electric machine, when the current is weakened the electro-magnets are also weakened. Let us suppose, for the sake of illustration, that the current has to feed an arc lamp, and suddenly a piece of one of the carbons springs off, thereby increasing the resistance. The current will decrease, and the machine will furnish a weaker current just at that particular moment when a stronger current is required to maintain the lamp burning. Although the lamp might not go out, a change in the intensity of the light will certainly be produced. As we have already seen, it was

for this reason that Wheatstone placed the electro-magnets in shunt, so that the circuit of the magnets should be separated from that of the armature and receiver. Brush makes the outer circuit independent of the intensity of the magnetic field by providing the electro-magnets with coils of much thinner wire in addition to the ordinary coils, the ends of which are connected with the collecting brushes. Marcel Deprez obtains current regulation along with the distribution, and aims at securing (1) that each portion of the apparatus shall receive the necessary current, and shall act independently of the others; (2) that the necessary regulation shall be executed by the machine itself; (3) that this regulation shall be of such a kind that the machine produces only such current as is required for the apparatus inserted in the circuit.

It follows that as the total amount of electrical energy is the product of E. M. F. multiplied by the quantity (*see* page 221) a variation in the total energy might be brought about either by altering the E. M. F., or by altering the quantity of the current, or by altering both. Deprez takes only the first two cases into consideration, and shows that to vary the electro-motive force with constant current strength requires the parts of the apparatus to be joined in series. To vary the current strength with constant E. M. F. requires the parts of the apparatus to be arranged in a divided circuit.

By again referring to the analogous case of a flow of water, the reasons for this difference of arrangement may be made clearer. Let us suppose that the energy of a waterfall is to be utilised by means of several hydraulic motors, which may be arranged either one above the other, or side by side. In the first case each motor would obtain the same quantity of water, but only a portion of the height through which the water falls would be utilised by each one. If more motors were to be driven in the same way by the same stream, the head of the water would have to be raised so as to fall through a greater distance, in order to admit of a greater number with the same difference of level for consecutive motors. This would correspond to a joining in series. In the second case the motors stand side by side, and the force with which the water comes down is the same in all the motors. Each uses the force due to the whole height, but receives only a fraction of the total. If now the number of motors is to be increased in this case it is evident that the quantity of water in the water-fall has also to be increased. This arrangement represents joining parallel.

This method of regulating the current has been applied in practice by Deprez in the following manner: The electro-magnets of the machine furnishing the current have two separate circuits, the coils of which run parallel to each other; so that the currents of both systems of coils flow in the same direction and consequently aid each other. Through one of the circuits flows a constant current, which is furnished by a separate source of electricity, as shown in Fig. 321. Into the second circuit of the electro-magnets flows the total current produced by the principal machine and utilised in the outer circuit when the parts of the apparatus to be supplied with the current are put in shunt. Only a branch current reaches the apparatus when it is put in series. Let us

first consider the joining in parallel arrangement. There are always two E. M. F.s active in the principal machine: the one produced by the independent generator, which is invariable, and which is proportional to the internal resistance (also invariable) of the lighting machine; the other, which is variable, and is produced by the lighting machine itself. When a certain number of parts joined parallel are active in the circuit, the resistance and current in the total circuit will depend on the number of these parts. If now one of the

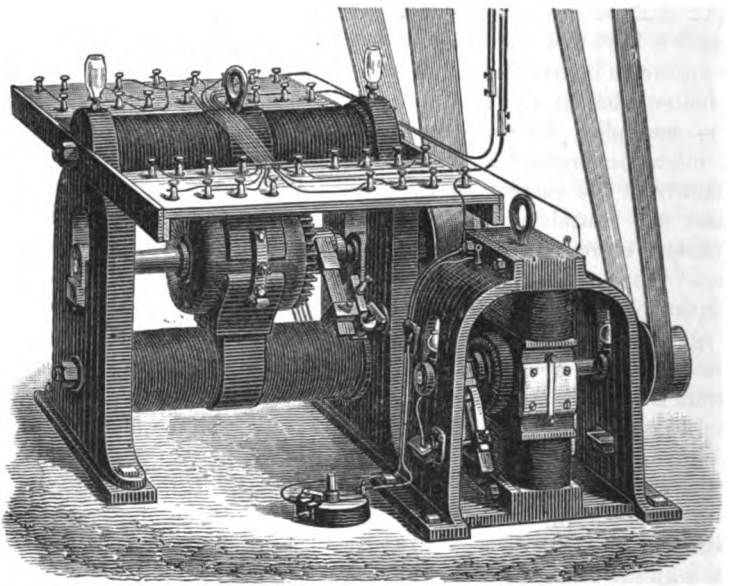


Fig. 321.—Deprez's Method of Regulation.

parts be taken out, the current loses one of the parallel passages; hence it finds a greater resistance. But since the current is inversely proportional to the resistance, it follows that the current must decrease. The reverse takes place when the number of parts employed is increased. For every fresh part inserted the current finds one more passage, that is, meets less resistance, and is therefore increased. By means of the above arrangement a self-regulating system to some extent is obtained.

When the parts of the system that use up the current are joined in series a constant current will flow through the circuit of the electro-magnet furnished by the generator; and through the second circuit, which is parallel to that of the principal machine and apparatus, flows a branch current, the strength of which is inversely proportional to the resistance of this branch circuit. If now one or more parts be added, the resistance in the outer circuit will be increased,

because the current has to pass through a greater number of parts one after the other, and has therefore to overcome a greater resistance. But increase of resistance in the outer circuit across which there is a shunt, causes also increase of current in the shunt the resistance of which remains unchanged. Therefore the electro-magnets, which in this case are in the shunt, will become more powerful, and the current in the outer circuit will thereby be increased. The strength of the current diminishes in the outer circuit in a similar manner when the number of parts is diminished. Hence by shunting the electro-magnets the

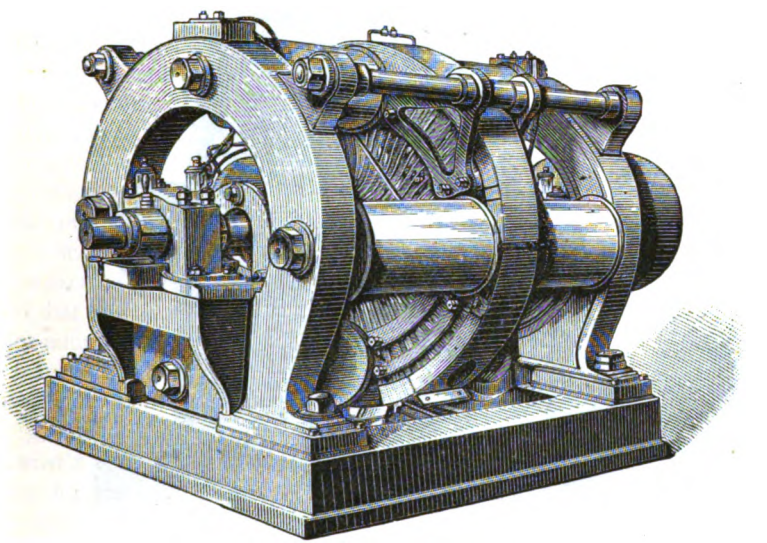


Fig. 322.—Schuckert's Compound Machine.

current of the principal machine is regulated without needing any further apparatus for the purpose.

Compound Machines.—When the resistance in the external circuit has reached a certain limit or the circuit is broken, the currents induced in the armature by the residual magnetism of the electro-magnets cannot reach the coils of the magnets, the increase of the current cannot take place, and the magnets receive no augmentation of their power. If, however, the electro-magnets are in shunt, their power will be increased when the resistance increases in the external circuit. The shunt machine, therefore, is capable of working with varying resistances in the external circuit, and may be used for glow lamps provided the power of the electro-magnet is regulated according to the number of lamps. Edison, as we shall see later on, obtains this adjustment by inserting varying resistances in the circuit of the electro-magnets. The shunt machine,

however, works advantageously only with a certain resistance. As the lamps are put out in succession, the resistance in the external circuit will become larger and larger, and the currents in the shunt circuit and electro-magnet coils increase more and more. The remaining lamps, therefore, will burn brighter and brighter, and might finally be destroyed. The two methods of joining them show, so to speak, an opposite behaviour. With dynamo-electric machines a small number of lamps can hardly be made to burn at all, while by using shunt machines with the same number of lamps, the

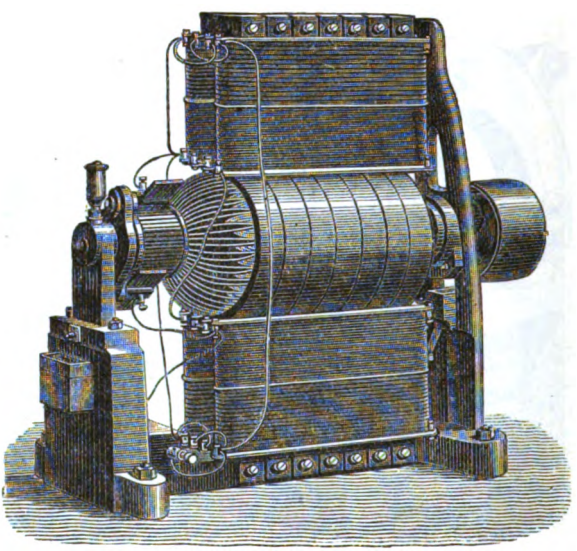


Fig. 323.—Siemens and Halske's Compound Machine producing constant E. M. F.

lamps run the risk of being destroyed on account of the heat produced. Engineers, therefore, have adopted a middle course between the two. Machines have been constructed by R. C. Crompton, Siemens and Halske, and S. Schuckert, upon this compound principle. Fig. 322 represents a compound machine by Schuckert, intended for about 400 Edison lamps. Figs. 323 and 324 represent a compound machine by Siemens and Halske. These machines differ from those already described only in the coiling of their electro-magnets. This is also the reason why compound machines have not been considered with the other machines, but under this heading of current regulation. In Figs. 323 and 324 the double coiling of the electro-magnets is extended in such a manner that each wire takes up half of every magnet-arm. In practice the arms might be arranged in pairs having thin and thick wire alternately, or the different wires might be coiled one over the other.

The mode of joining up the generator and circuit may easily be understood from Fig. 324. The coils consisting of strong wire are in parallel arrangement, the coils consisting of thin wire are joined in series. The simple arrows indicate the direction of current in the thick, and the plumed arrows indicate the direction of current in the thin wires. P and P_1 are the pole-clamps of the machine, to which the outer circuit is joined; B B_1 are conducting brushes which slide upon the commutator. The machine can supply from 100 to 200 Siemens glow lamps, each of 16-candle power. This compound machine, which may be regarded as consisting of a dynamo-electro machine with a shunted auxiliary machine, is capable of regulating the current without any further apparatus, and works uniformly with varying resistance in the outer circuit, provided that the number of revolutions per minute is constant. Compound machines, therefore, are well adapted for the distribution of electric energy from a centre.

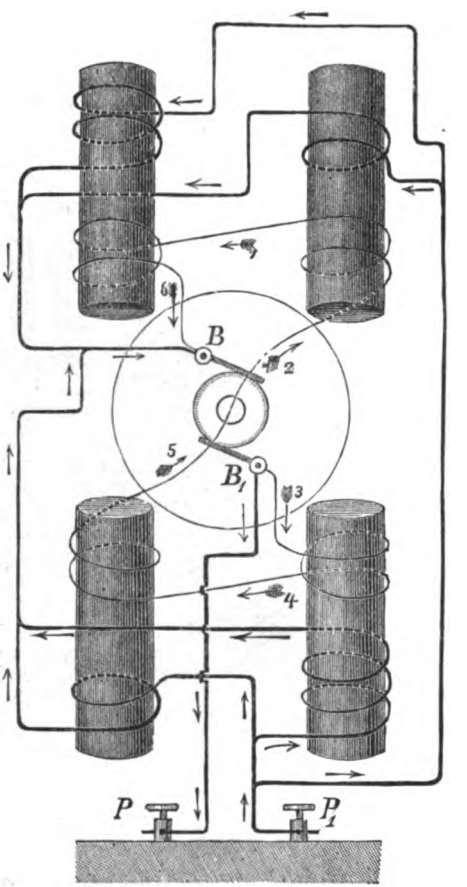


Fig. 324.—Diagram of Siemens' Machine.

Maxim's Regulator.—Special apparatus for the regulation of the current have become of less importance since the construction of compound machines. Two regulators were exhibited during the Paris Exhibition, one by Maxim, the other by Lane-Fox. Maxim regulates the current of the lighting machine by varying the current of the auxiliary machine, by adjusting the contact brushes of its commutator. Each brush has two positions; one corresponds to the maximum strength of current, the other to the minimum strength of current; when in the latter position the brushes stand in the so-called neutral line; by moving the brushes from or towards the line, the current of the dynamo-electric machine will be altered. Fig. 325 represents the practical application of this principle. An electro-magnet E_1 of great resistance is fixed on the inducing machine, and is inserted in the outer circuit. This magnet attracts the armature A with a force proportional to the strength of the current. The spur *f* which is

connected with A moves between two wheels *r* and *r* without touching them, as long as the current which passes through the coils of the magnet has its normal strength. When the current becomes weakened by more lamps being lighted, etc., the armature A then rises because the magnet has not the

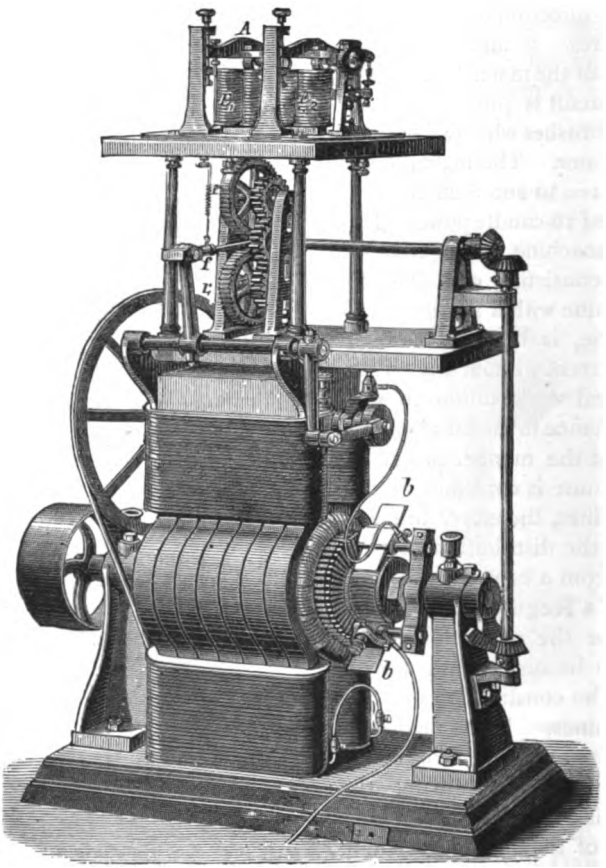


Fig. 325.—Maxim's Regulator.

necessary force to hold it down. The armature *f* is also pushed upwards, catching with its upper tooth the teeth of the wheel *r*, and moving the latter forward by one tooth for every backward and forward motion.

This motion is transmitted to the brushes *b b* by properly adjusted wheels, which causes the latter to leave their first position and to assume the position most favourable for the strength of the current. Motion in the opposite direction takes place when the current has become too powerful in consequence

of the extinguishing of several lamps. The second electro-magnet E_2 serves as a safety valve. The armature can only be attracted by this magnet when the current becomes very powerful; in this case the prolongation of the armature meets a platinum contact, which causes the electro-magnet coils to be taken out of the circuit, and thus damage to the apparatus (that is, to lamps, etc.) is prevented. The interruption of current, however, lasts only a very short time, because through the interruption the electro-magnet E_2 loses its force immediately and lets the armature go. By this means the normal condition

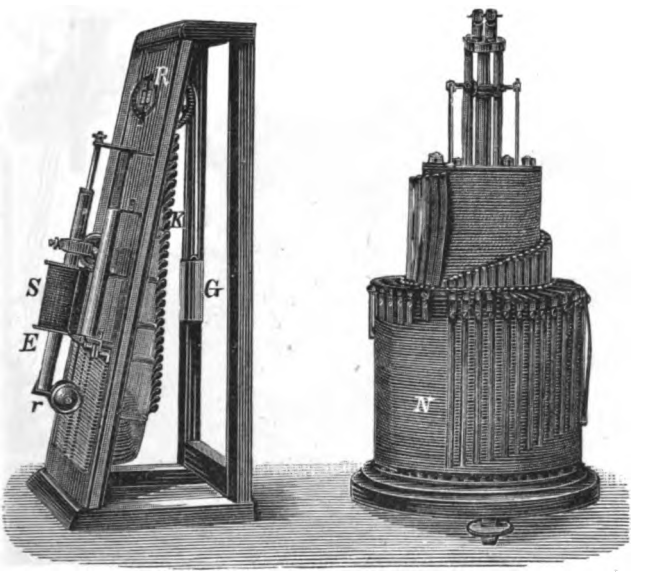


Fig. 326.—Krizik's Regulator.

of the machine is again restored. As the electro-magnet E_2 has only occasionally to effect the regulation, and the electro-magnets of the principal machine do not entirely lose their power, the lamps will not go out, but their brightness will diminish. The electro-magnet E_2 gives, so to speak, time to the electro-magnet E_1 to bring into action its regulating apparatus. The same principle, viz. the adjustment by means of the contact brushes of the commutator, was followed in another apparatus constructed by Maxim, varying in some matters of detail from the one just described. Maxim has also constructed a regulator having for its essential parts a long movable rheostat with sixty resistance cylinders, in form and arrangement similar to the ring of a Gramme's machine. This regulator is inserted in the circuit of the inducing electro-magnets. As the ring is moved in either one direction or the other by means of an electro-magnet, at the same time a larger or smaller number of

resistance cylinders are brought into the circuit, causing a decrease or increase of current.

Fig. 326 represents two regulators constructed by Krizik. A solenoid S influences the iron cone E enclosed in a brass tube, according as a strong or weak current flows through it, the attraction of the iron core being uniform in all its positions as regards the coil in consequence of its conical shape. The attraction of the solenoid is balanced by the weight G which hangs from the pulley R. The iron core moves either up or down the inclined plane of the frame,

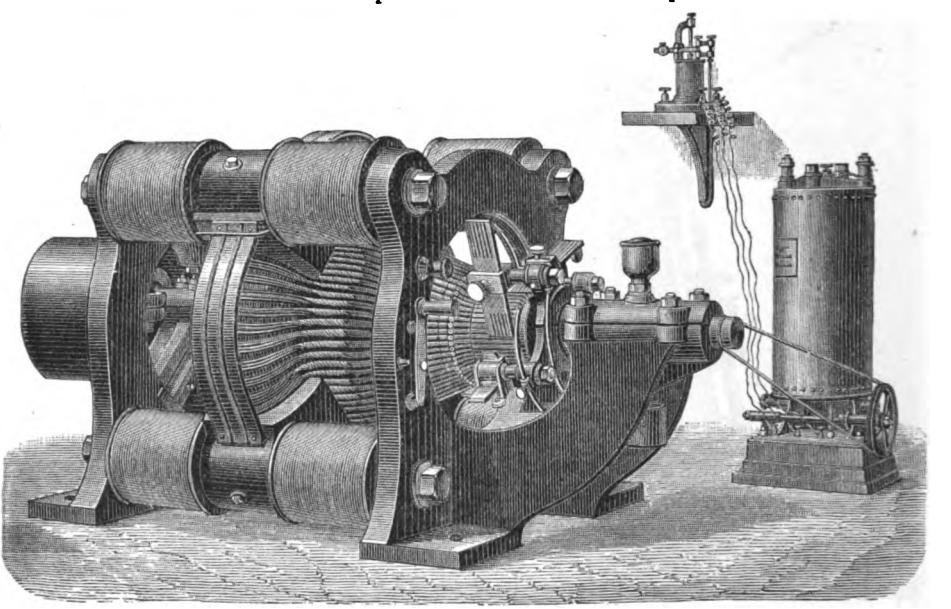


Fig. 327.—British Machine with Regulator.

according as the weight G or the attracting force of the solenoid prevails, and at the same time the contact roller *r* moves over a number of contact strips which are connected with carbon rods K. In this manner, when the current is increased, the iron core is drawn deeper and deeper into the solenoid, and more and more carbon rods are inserted in the circuit. If, however, the current becomes too weak, the counter-weight G pulls up the iron core, and at the same time takes out resistance rods, thus allowing the current to increase to the desired strength.

The Anglo-American Electric Light Company use a rheostat consisting of carbon discs, for the regulation of current in their machines, and a similar plan is employed in what is called the British regulator, shown in Fig. 327. A few minor points being excepted, it is like a four-pole Schuckert machine. The manner of working of the British regulator may be better understood by

studying Fig. 328 (from "La Lumière électrique"). Connected with the pole-clamps *i h* are, on the one side, the lamps or other apparatus in the outer circuit *i h*, and on the other side the electro-magnets E, the carbon disc, and rheostat R. At I and II a branch circuit joins the circuit, which contains the electro-magnet *d*, the iron core of which is carried by the lever *c*. The right arm of the lever rests between the contact pins *a* and *b*, and the forces of attraction are opposed by a weight G and the spring *r*. When the

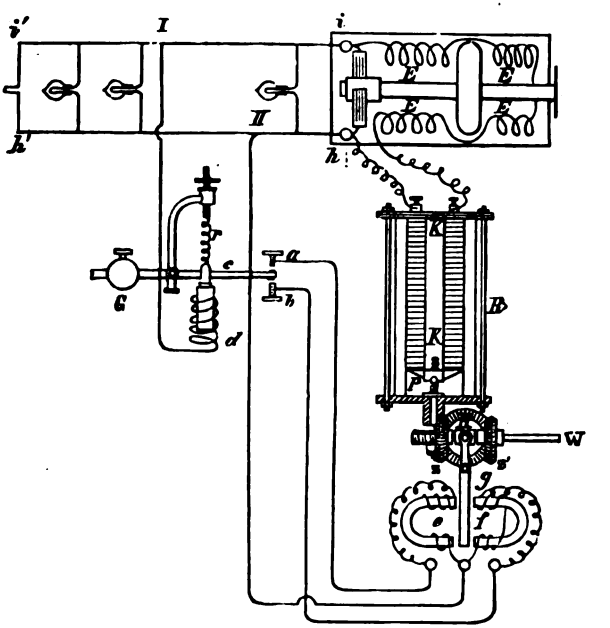


Fig. 328.—Diagram of Regulator.

lever touches the pin *a* the electro-magnet *e* will be inserted in the branch circuit, and when it touches the pin *b* the branch current will flow through the coils *f*. The armature *g* will therefore be attracted by either *e* on the left, or *f* on the right. Keyed upon the shaft W above the armature are the wheels *z z*, which are maintained in motion. (Compare Fig. 327.) Between these wheels is another wheel H, the teeth of which will catch the teeth of either *z* or *z'*, according as the armature *g* moves to the right or left. The armature *g* is lengthened beyond its fulcrum, and the projection causes the connection of the wheel H with either *z* or *z'*. The wheel H pushes a plate either up or down, causing increase or decrease of contact between the several carbon discs K of the rheostat; and thus increasing or decreasing the current. When the current in the outer circuit surpasses the required strength, the force of

attraction of the magnet *d* will become greater than the force of the spring *r* and the weight G. The right side of the lever C therefore must move down, and coming in contact with *b* will cause the insertion of the electro-magnet *f*. When the armature *f* moves to the right its projection beyond the fulcrum moves to the left, and couples *z* and H. This causes the plate P to move down and widen the contact between the carbon plates K K, *i.e.* increases the resistance of the rheostat. The latter being in the same circuit with the electro-magnets E E, this increase of resistance causes the current flowing through the coils of the electro-magnets to diminish, and thus diminishes the current of the machine. When, on the contrary, the current has become too weak, the lever C will be lifted by the spring *r* and the counter-weight G, contact will be made at *a*, making the electro-magnet *e* active, and causing H to move in the opposite direction. The plate P is lifted, presses the carbon plates against each other, and diminishes the resistance of the rheostat, which consequently causes an increase of current. We need hardly mention that with the required strength of current the lever *c* rests between *a* and *b*, and the armature *g* between *e* and *f*, and therefore the wheel H remains at rest.

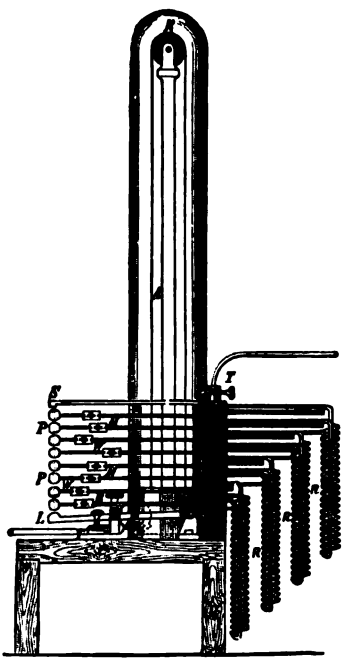


Fig. 329.—William Siemens' Regulator.

Siemens' Regulator.—Fig. 329 represents a regulator devised by Sir William Siemens, based on Joule's law, and acting by means of the expansion and contraction of a ribbon of metal through which a current passes. A very thin metal strip A has one end fastened to the screw B, which regulates its tension. This runs over the pulley R, and has its other end attached to a lever, which carries the contact arm L, the position of this arm depending on the length of the strip A. Above this contact arm a series of arms M is arranged, which have at their free ends the contact bars P. The distance of the latter from each other is regulated by the movable weights W. The other ends of the contact arms are in connection with the resistance coils R, made of German silver. The spring S, which has also a contact bar, is connected with the pole-clamp T. When a current passes through the strip A it will become heated in proportion to the square of the strength of the current, causing the strip to expand, and also causing the lowering of the lever L and levers M successively. The contact of their bars will be broken (as shown in the figure), and the resistances R will be gradually inserted. When the current diminishes, the strip A cools, contracts,

and lifts the lever L so as to cause the bar P to make contact and take out the corresponding resistances R. When all the bars are in contact the current will flow directly from the clamp T to the lever L. To prevent radiation from the strip A it is surrounded by a glass case, and the whole apparatus is placed in a room at a moderate temperature.

Edison's Method of Regulating Current.—Edison distributes electricity from his central stations by using the shunt system. In order to regulate the total amount of generated electrical energy according to the requirements by this arrangement, the E. M. F. is kept constant by varying the strength of current. Edison brings this about by varying the intensity of the magnetic

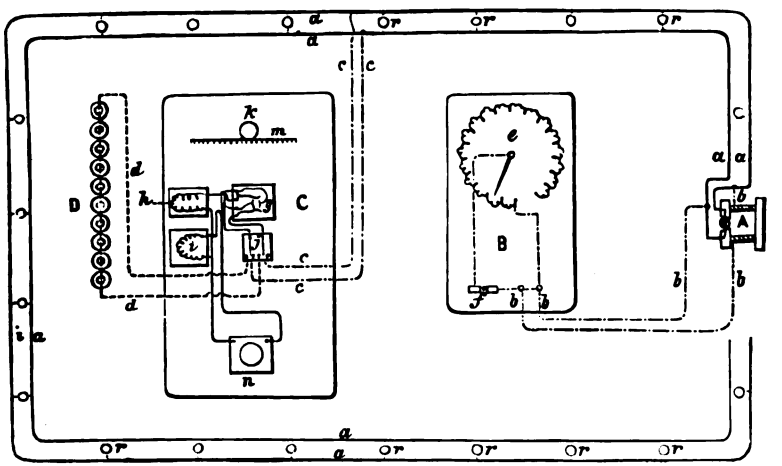


Fig. 330.—Diagram of Edison's Method.

field in which the armature rotates. For this purpose the coils of the electromagnets and a series of resistance coils are put parallel to the circuit in which the lamps are placed. By the insertion of resistance coils in this circuit the strength of the current in the coils of the inducing electromagnets will be diminished, in this way altering the intensity of the magnetic field. The insertion and taking out of resistances is brought about automatically. The apparatus represented in Fig. 330 consists of two groups, one of which is to measure the strength of current in the circuit, the other to regulate the current according to these measurements. From the machine A the current flows through the conductors *a a* to the several lamps *r*. The parallel circuits *c c* lead to a commutator *j* of four contacts. This is connected with *g*; *h* is a resistance box, and *i* is a constant resistance of 50,000 ohms. The circuits *d d* of the standard battery D, of 110 volts, lead to the commutator *j*; *n* is a Thomson's mirror galvanometer, *k* being the lamp

of the galvanometer, and *m* the scale. The current regulator B is connected by means of the conductor, *b b* with the coils of the inducing magnet of the

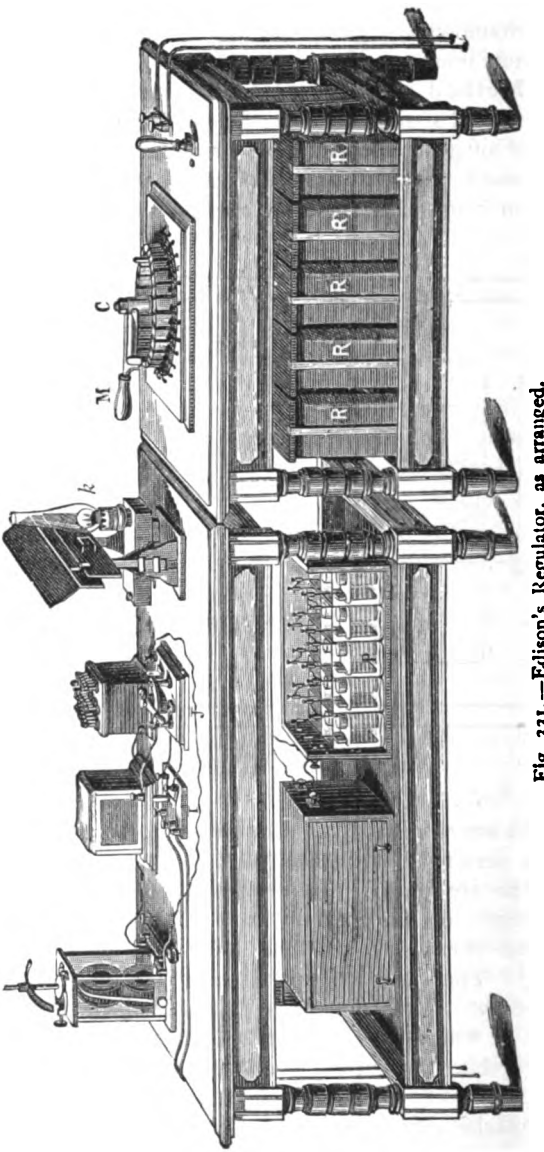


Fig. 331.—Edison's Regulator, as arranged.

machine A. At *f* a contact-breaker is inserted into the circuit. *e* is a contact lever moving in a circle and connected with C. By touching one of the contacts

also arranged in a circle, the circuit *b b* is closed, causing the current to pass through a larger or smaller number of resistances. For the regulation of the current two distinct operations are necessary; the measuring of the current in the working circuit by means of the apparatus C D, and the insertion of a smaller or a larger resistance in the circuit of the inducing magnets, by adjusting the lever *e* according to the measurements obtained. Fig. 330 will make this clear. To measure the current, the arm of *j* is moved to the right. A branch current will now flow from *a a*, through *c c*, through *j g*, through the constant resistance *h* and variable resistance *i*, to the galvanometer *n*. The constant resistance *h* of 50,000 ohms is inserted so that the galvanometer does not get the full strength of current, but a small fraction of it only. The varying resistance *i* further diminishes the strength of the current when it is found to be still too large for measurement by the galvanometer. The current passing through the galvanometer causes a deflection of the needle proportional to its strength, which is read off from the scale *m*. The scale is so arranged that one volt causes a deflection of three divisions. It is necessary occasionally to test the accuracy of the scale and to find out whether the current has the nominal strength it is, compared with the current of the standard battery D, which is inserted for this purpose in the galvanometer circuit by moving *j* towards the left. The current of the battery when brought into the circuit flows through *j g h i* to the galvanometer. If now the deflection of the needle is the same as in the first reading, the current has its normal strength; if the deflection is not the same, it must be made the same by inserting resistances by means of the apparatus B. The contacts arranged in a circle are the terminations of a series of resistances represented in Fig. 331, under the table at R, consisting of parallel boards held together by four rods, upon which bright copper wires are coiled. This arrangement of the resistance is chosen in order to avoid heating the wires. By moving the arm M C (*e* in Fig. 330) a larger or smaller resistance is inserted. The current might be regulated by inserting the resistance in the outer circuit, but in this case there would be loss of energy. Edison therefore inserts the resistance in the circuit of the inducing magnets, and by doing so weakens the inducing effects, and consequently the inducing current which has to do work in the outer circuit. This causes no loss of energy, for the chief work of the motor consists in overcoming the forces of attraction between magnet and armature, that is to say, in moving the armature. When the force of the magnet is weakened the motor has less work to do. To prevent the speed of the motor increasing whenever the resistance diminishes, the motor has a regulator which causes the velocity of the motor to remain constant by admitting steam into the cylinder.

To regulate the current in the way described, an attendant has to watch the galvanometer, and arrange the resistance as required. Following the plan used by Maxim, Lane-Fox, and others, Edison constructed an apparatus for the regulation of current, shown in Fig. 332, which inserts the required resistance automatically. This regulator consists of a kind of relay C, and the electro-magnets A and B,

the pole-pieces of which are attached to the ends of the beam of a balance. The lever of the electro-magnet C moves between the two contact-breakers J and K, and is able to bring the electro-magnet A or B into the circuit, in consequence of its touching either of the contact-breakers. The beam of the balance, which bears the pole-pieces of these magnets, is provided with a tongue E, the spring of which is able to slide over a series of contact strips, which are successively connected with increasing resistances.

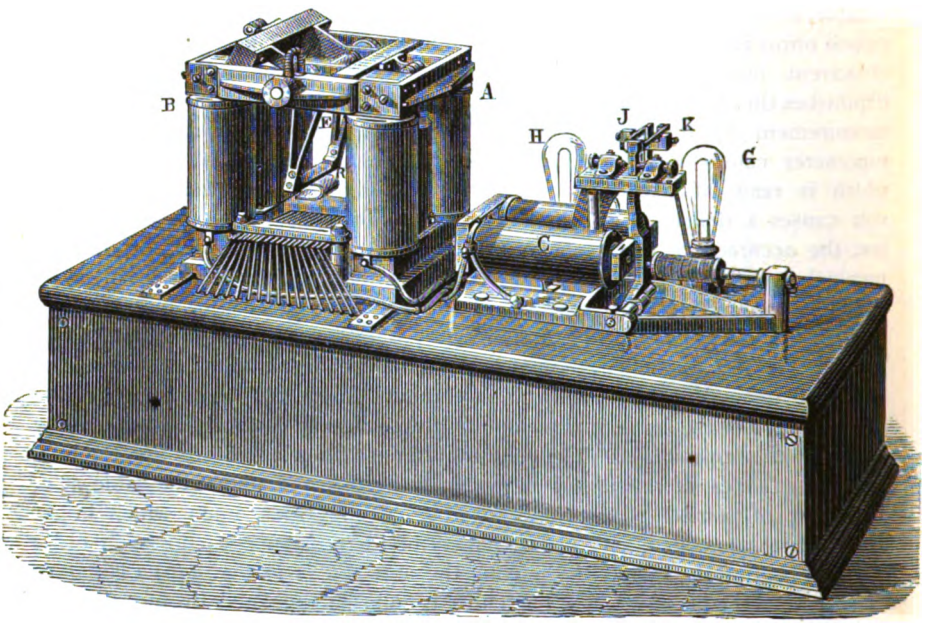


Fig. 332.—Edison's Automatic Regulator.

Supposing the working current to be of normal strength, the position of the lever of the magnet C is midway between the two contact pieces, and the magnets A and B remain without currents. If, however, the current is less or greater than the normal strength, the lever is repelled by the electro-magnet C and closes the contact-breaker K, or is attracted more powerfully by the magnet C and closes the contact-breaker J. In both cases one of the magnets A or B, together with its coils of wire, is brought into the circuit, and the beam of the balance is thus turned in one or the other direction. The spring R will continue to introduce greater resistances into the circuit of the electro-magnets of the machine, or to remove greater resistances, until the normal strength has been attained.

In order to bring before the attendant the motion of the spring R quite clearly,

the two lamps G and H have been fixed to the apparatus; the colour of the glass of one of these lamps is blue, that of the other red. The lever of the magnet C has the effect of bringing the red or the blue lamp into the circuit.

The Lane-Fox Regulator.—The regulator which Lane-Fox exhibited in the Exhibition at Paris is similar to that of Edison, which we have just described. A relay brings one of the electro-magnets, which are provided with a common pole-piece, into the circuit, and thus effects a motion of the pole-piece in one or the other direction. Thus also two tooth-wheels, resting on a horizontal axis, and enclosing another tooth-wheel fixed upon a vertical axis, are moved to the one side or the other, and thereby one of them is brought in contact with the wheel fixed on the vertical axis. The last-named wheel receives impulses from the vibrating pole-piece of a magnet, which constantly turn it in one direction. The rotation is transmitted to the horizontal axis of the pair of tooth-wheels, causing them to turn in one or the other direction, and causing a lever upon the same axis to slide over a series of contact-breakers, which form the ends of the resistances.

The Regulator used by Schwerd and Scharnweber consists of two solenoids, into which a pole-piece of the form of a horse-shoe is inserted; the latter is suspended from a piece of tape which passes over a pulley, and has a weight attached to its other end. The pole-piece therefore moves into the solenoids or moves out of them, according as the strength of the current exceeds the strength required, or falls below the strength required. A cylinder resting on the same axis as the pulley takes part in its rotation. Above the cylinder there is a succession of contact springs, as the ends of a series of resistances, which rest upon a piece of the form of a helix upon the cylinder, and thus the different contact springs are lifted up in succession. Thus resistance is introduced or removed, according as the cylinder is turned in one or the other direction—*i.e.*, according as the pole-piece moves into the solenoids or moves out of them; in other words, according as the working current has become too strong or too weak.

Gravier's Regulator.—The regulator which A. Gravier uses is shown in Fig. 333. The negative pole-clamp of the machine U is connected with earth. From the positive pole wires R lead to the different places of consumption. The parts of the apparatus are connected on the one side with the circuit, on the other side with the earth. The negative pole-clamp of the machine is further connected with the electro-magnet A B of the regulator by means of a thin wire. From *v*, the remotest point, leads a thin wire, the so-called return wire, which is connected with the coils of the electro-magnet A B. A current will therefore flow through the electro-magnet A B, the strength of which will correspond to the consumption in the distributing wires, work of the machine U being uniform. The electro-magnet A B indicates, therefore, by the strength of its current, the strength of current required in the outer circuit. The shoe A terminates in an edge upon which the iron beam *b b'* can turn; *b b'* forms, so to say, the continuation of the pole A, so that at *b'* and B two

opposite poles stand opposite each other. The forces of attraction of these two poles are balanced by the weight P so long as the current in the outer circuit has the desired strength. When the current decreases, the weight P moves downwards, which causes contact of the two springs t' and c'. Increase the current beyond the desired strength, and the force of the magnet A B will

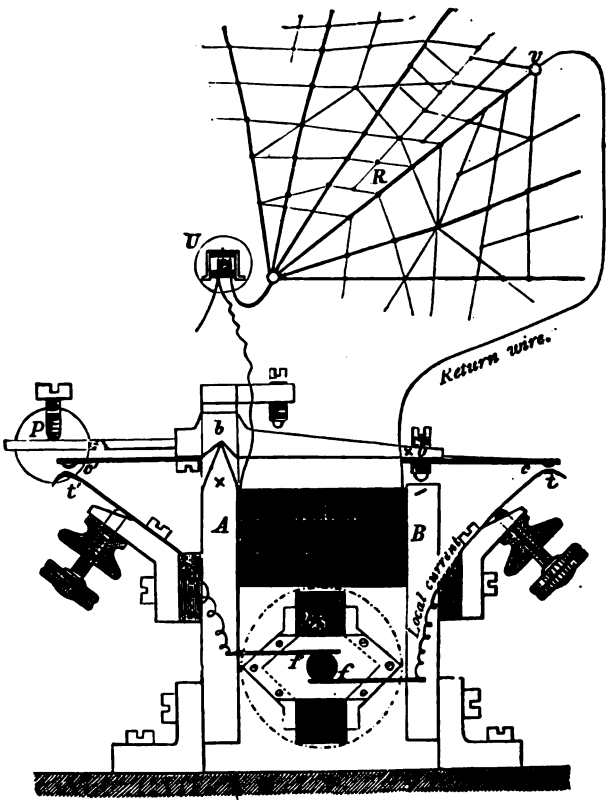


Fig. 333.—Gravier's Regulator.

prevail, and will draw down $b\,b'$, causing contact of the spring $c\,t$. In both cases a local current is closed, which flows through the contact springs $f\,f$ into the coils B S. B S will move in one or the other direction according to whether the current enters through $c\,t$ or through $c'\,t'$, which is determined by the strength of current in the distributing wires. The motion of B S indicates their strength of current, and may be used for the regulation of it. For this purpose the coil has at one end an endless screw, which sets a wheel with teeth in motion; this wheel either varies the speed of the motor or the resistance in the circuit of the electro-magnet.

Regulation by Secondary Generators.—The apparatus we have now to describe differs from the preceding apparatus for the regulation and distribution of current, in being part of the outer circuit instead of being attached to the

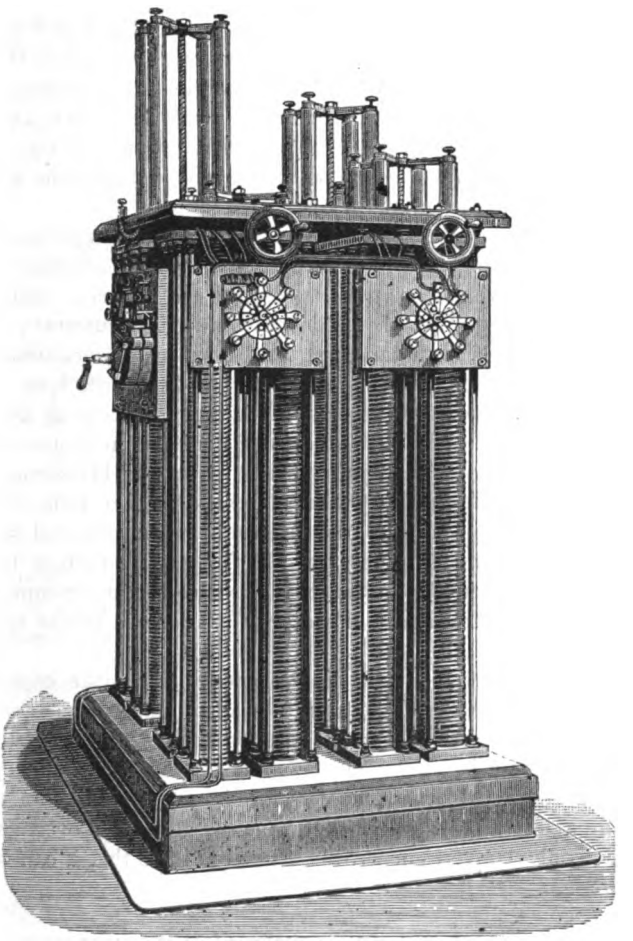


Fig. 334.—Gaulard's Secondary Current Generator.

generator. By its means, currents having a certain strength are altered at the place of consumption according to requirements. To this class of apparatus belong the secondary generators of Gaulard and Gibbs, which receive the current near the place at which it is to be used, and, after converting and re-converting it, give it up for use as required.

To convert primary into secondary currents, as with every other conversion

of energy, must always be accompanied by loss. The secondary generators of L. Gaulard, represented in Fig. 334, consist of sixteen vertical pillars, fastened between two wooden boards by means of two iron bolts. Each of these pillars is a coil of cable made in the following manner :

A copper wire, 4 millimetres in diameter, is insulated and surrounded by forty-eight wires 0·5 millimetre in diameter, arranged parallel to the axis of the thick wire. The forty-eight fine wires are separated into six groups, each consisting of eight wires. The thick wire has a small resistance, and is used for conducting the primary current. The different groups of fine wire conduct the secondary current. A series of commutators above unite the several primary and secondary coils in groups as they may be required.

Haitzema Enuma inserts induction coils in the primary circuit, and either uses the induced currents in feeding lamps, etc., or for the further generation of induced currents, in which case tertiary currents are utilised. Induced currents of still higher order might be obtained from the tertiary currents ; it is, however, difficult to understand how this method can be practically economical, as every such reconversion of the currents must be accompanied with loss.

The plan of using induced currents for lighting or securing the distribution of the current is not new, and several electricians have made use of it : Charles Bright in 1852, Jablochkoff in 1877, Fuller in 1879, and Haitzema in 1882.

Regulation by Secondary Batteries.—Another form of regulator is found in the Secondary Batteries referred to in page 160, and more fully described in a subsequent chapter (see page 427). As the current lasts until the oxidised lead is again reduced to the metallic state, the more complete the conversion of the lead electrode into dioxide, the greater will be the quantity of the charge returned.

Secondary batteries, when sufficiently improved, will make capital regulators. They can be inserted in the circuit, and will absorb electric energy at one time, and yield it up again to feed the lamp, independently of the generator, at another time. Although the using of secondary elements involves the introduction of a transformation between the source of electricity and its place of consumption, and therefore a loss of energy, yet they have the advantage over induction coils, that they not only convert energy, but also store it, so that it can be used again when required.

CONDUCTION OF CURRENT AND REGISTRATION.

Conductors.—We have already pointed out that every conductor conveying electricity is required to offer no more resistance than is necessary to be well insulated, and to be placed so that it will be protected from injury.

We must next consider the most convenient sizes and other qualities of conductors which have to convey the powerful currents used for lighting, and for the transmission of power, etc. etc.

The material generally chosen for conductors is copper. If the conduction

of silver be taken as 100, then, according to Matthiesen, that of copper will be 77·43, that of zinc 27·39, that of iron 14·44, that of platinum 10·53, that of German silver 7·67, that of mercury 1·63, and that of carbon 0·0386. The thickness of the conducting wire must be regulated by its length and the strength of the current it is to carry, and the purposes it is to serve.

Zacharias gives for simple lights the following sizes:

100	200	300	400	600	metres total length.
3	4	5	6	7	millimetres cross section.
7·06	12·56	19·63	28·27	38·49	kilogrammes weight of wire.
0·24	0·26	0·255	0·232	0·258	ohms resistance.

The following table is for lamps in series, or several series joined parallel:

For one Machine of		By a Resistance in ohms.	Number of Lamps to be fed.		
Difference of Potential in volts.	Strength of Current in amperes.		Edison's Lamps of 8-candle power.	Joined parallel in Groups.	For Arc Light per 1,200 N.
55	7	0·6	10	1	—
105	8	0·6	22	2	2 to 3
160	8	1·2	33	3	4 to 5
265	8	2·0	55	5	6 to 8
420	8	2·5	88	8	—
630 to 730	8	4·0	132 to 154	12 to 14	8 to 12

For glow lamps of sixteen standard candles which are to be joined parallel, or glow lamps of eight standard candles joined up two and two in series, the following dimensions are given:

Length of conductor in metres	100	200	300	400	500	600	700	800	900	1,000
Cross section in millimetres	0·785	1·57	2·36	3·14	3·93	4·72	5·5	6·28	7·07	7·85
Diameter in millimetres ...	1	1·4	1·7	2·0	2·3	2·5	2·7	2·8	3·0	3·2

For compound machines the resistance in the circuit is but small.

The limit of resistance for a Schuckert compound machine is as follows:

Model	IL½	IL1	IL2	IL3	IL4	IL5	IL6
Resistance in ohms... ...	0·70	0·30	0·20	0·10	0·07	0·05	0·018

The above figures can only be considered approximately correct. For the calculation of the resistance in a circuit tables may be consulted, but it is far better to determine the resistance experimentally in each particular case.

A. V. Waltenhofen found, for instance, the following resistances in ohms for different copper wires of 1 millimetre length by 1 square millimetre in cross section:

Wire	Ia	IB	II	III	IV	V	VI
Resistance	0·025	0·036	0·034	0·024	0·103	0·041	0·026

The large resistance of wire IV is explained by the fact that, although sold for copper wire, it was found to consist of an alloy of copper containing a large quantity of zinc. Apart from this species of adulteration, however, the re-

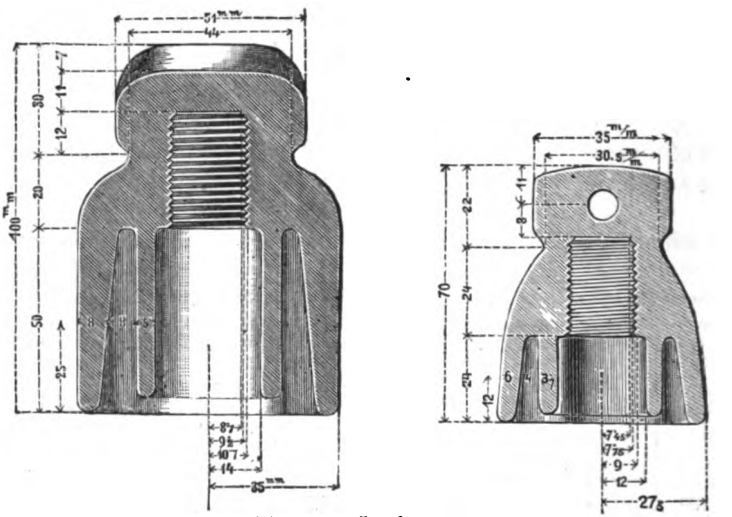


Fig. 335.—Insulators.

sistance of the other samples exceeds the resistance of copper by at least 41 per cent. Such specimens, therefore, should not be used for dynamo-electric machines, or for cables, as for these purposes a material is required that possesses at least 90 per cent. of the conductivity of pure copper. Wires in the open air need, as a rule, no insulating cover. Bright wires, or wire ropes of soft copper, are used, as hard and very thick wires are difficult to manipulate. A good form of insulator is represented in Fig. 335. Insulators of this kind are supported by a piece of wrought iron having the shape illustrated in Fig. 336. Underground wires are often to be preferred to overhead wires. Siemens and Halske have manufactured recently leaden tube cables, which consist of a copper wire of 3·4 millimetres diameter, covered alternately by lead and insulating substances capable of resisting mechanical and atmospheric influences, and these cables are also very cheap.

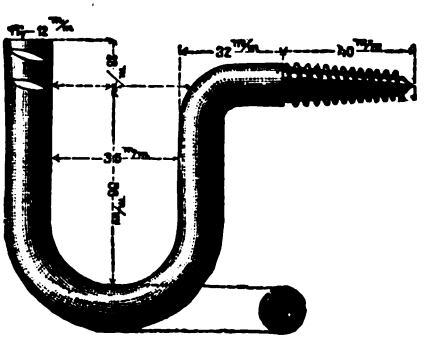


Fig. 336.—Insulator.

H. Geoffroy has suggested the insulation of copper wires by means of

asbestos, held together by lead sheeting. Asbestos is said not only to insulate, but also to conduct heat so badly that even when the wires are fused the lead sheeting remains uninjured. As yet, however, no practical use has been made of the suggestion. The conductors used by Edison consist of copper rods, whose cross sections are segments of circles (Fig. 337). These copper rods are placed in wrought-iron tubes, filled with insulating matter, and having on the outside tarred ribbons wrapped round them to prevent the oxidation of the iron. To hold the copper rods in position, perforated paste-boards are arranged at

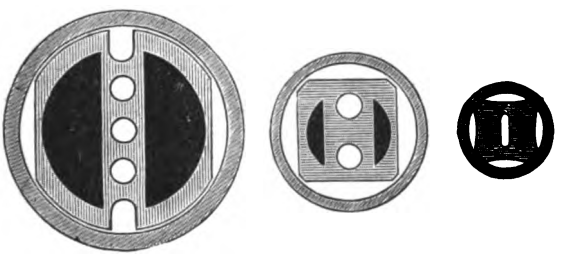


Fig. 337.—Edison's Tubes.

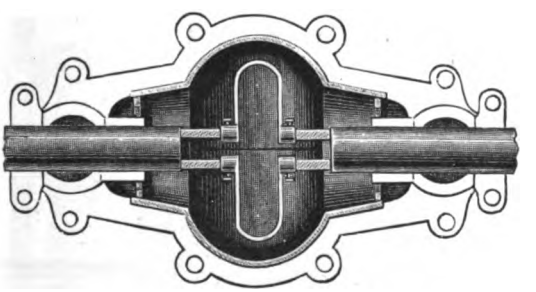


Fig. 338.—Edison's Union or Joint.

intervals. These conducting tubes are manufactured in lengths of 6 metres, and are connected with each other as shown in Fig. 338. The copper bars protrude about 5 centimetres from every tube, and are connected by means of a V-shaped piece, so as to allow of the expansion and contraction of the metal; the whole is covered up by a cast-iron box, which is filled with insulating matter. The sizes of the cross sections of the copper rods Q and diameter of tubes D are as follows:

Number	1	1½	2	2½	2¾	3	4	5	6	7
Q square millimetres ...	830	598	443	340	244	133	92	54	33	16
D millimetres... ...	82	76	70	65	58	57	48	33	33	28

The cross section of the conductor diminishes with the distance from the generator. The mode of connecting a branch conductor with the main con-

ductor is shown in Fig. 339. The copper bars of the main conductor are brought into an iron box, cut, and then connected with the branch conductor by means of a U-shaped piece. For branch conductors lying at right angles to the main conductor, the U-shaped piece takes the form of a rectangle. In a similar manner the wires leading from a room are connected (Fig. 340), but in

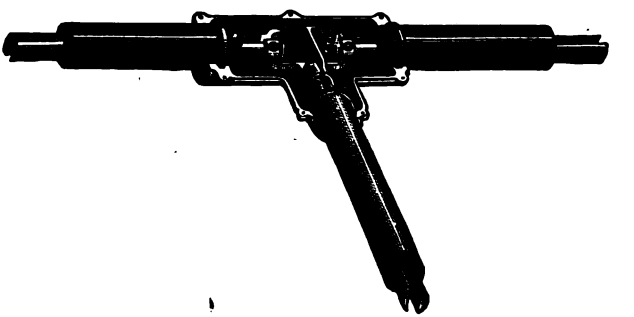


Fig. 339.—The T-Joint.

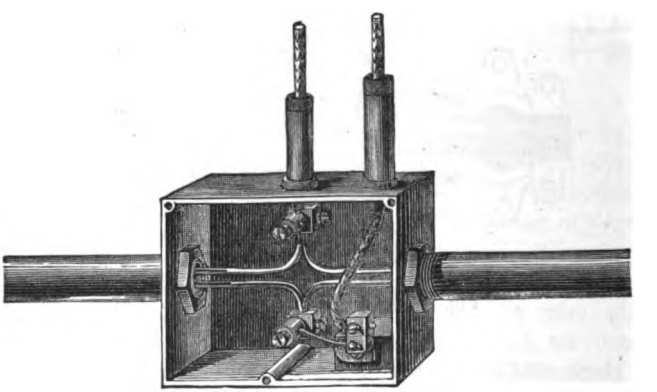


Fig. 340.—Branch Conductors.

this case the box is not filled with insulating substance, but is closed hermetically by means of a lid. The bent conducting wires within the box lead to clamps, and a piece of leaden wire is introduced between the lower clamp and a third clamp from which the wire of the room leads. The leaden wire is a safety arrangement to prevent dangerously strong currents from entering the room. Whenever the current becomes too strong, the leaden wire becomes heated and melts, and thus breaks the connection.

The wires used inside a building ought to have good fire-proof insulators. Various forms of clamps and binding screws for these wires are represented in

Fig. 341, taken from Uppenborn's "Calendar for Electricians." As a rule the clamps most frequently used are those lettered A, which have spaces cut out to let the wires through. These are fastened to the walls by means of wooden screws. When, however, the wires are to be carried by damp walls, double clamps like that in B must be used. When the supports may be very wet, the porcelain insulators D are needed.

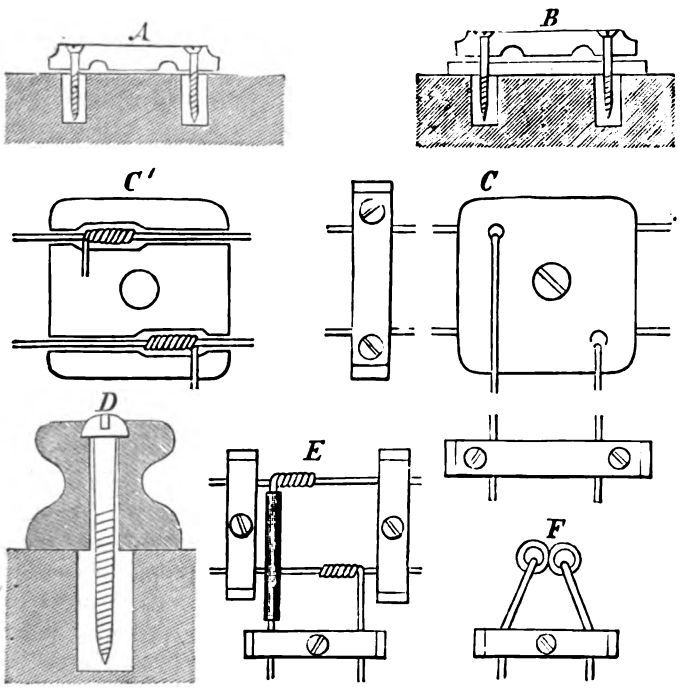


Fig. 341.—Clamps for Conductors used in Lighting.

The modes of connecting branch wires are shown in C, C', and E. Branches for less than five lamps are simply soldered together, covered with gutta-percha, and fastened with the wooden clamps E. When the wires have to pass through walls each wire has to be placed in a glass tube F_1, or both wires together are surrounded by gutta-percha covers well insulated from each other.

The increasing use of electricity has led to the framing of rules for the protection of human life, and for guarding against fire. The following rules, according to Uppenborn, are to be observed in Philadelphia:

1. All the wires conveying electricity within a building must be well insulated throughout their whole length.

2. At intervals such insulations as are liable to become damaged by the cutting through of the supports, etc., ought be inspected.

3. The wires are to consist of as few pieces as possible, and when joining cannot be avoided the junction must be well insulated and secured so as to prevent the separation of the parts, which might give rise to the formation of sparks.

4. Conduction by the earth is not safe; both back and forward conduction has to be performed by means of wires. The conducting wires must not be laid in the immediate neighbourhood of metallic or other conductors, such as water or gas pipes, etc. If the latter have to be crossed, careful and sufficient insulation must be provided.

5. The possibility of having the current short-circuited is avoided by having all the wires coming from the machine or parts of it kept well separated. All the wires are to be well fastened, and are only allowed to hang down when this is absolutely necessary for the suspension of lamps. Neither damp walls nor the floor should be used for fastening the wires.

6. The dimensions of the wires are to be such that the strongest current might be conveyed through them without heating them unduly.

7. Danger of losing life by the chance discharge of the current is to be avoided by arranging the wires so as to be out of reach, or taking care to have them well protected.

8. For large systems, such as those used at theatres, railway stations, etc., plans easily understood, and giving minute details, ought to be drawn and to be made accessible.

9. Competent persons only ought to be entrusted with the electrical engineering.

Methods of Measuring the Electricity consumed.—As the producer and the consumer of electricity are generally different people, it is necessary to have some method of measuring the electricity consumed in order to have it valued, as with gas. Such means of measuring and registering it have been constructed. Wilson measures the quantity of electricity by its effects. We know that the electric current decomposes metallic salts, separating out the metal at the negative pole and the acid at the positive pole. This separation of the products is directly proportional to the strength of the current, other things being equal. According to Ohm's law, the current increases in a closed circuit with the electromotive force, and it decreases as the resistance increases. Edison, by using a shunt system, secures that the resistance in the circuit will be the larger, the fewer lamps are inserted in the circuit. In Edison's system, therefore, we have a resistance inversely proportional to current, and also inversely proportional to the number of lamps inserted. But the amount of the separated products of decomposition in a voltameter is proportional to the current; it follows, therefore, that the amount of these products of decomposition must be proportional to the number of lamps burning. It must, therefore, be a measure of the amount of electricity consumed by the lamps. On this principle Edison has constructed several kinds of apparatus, one of which is represented in Fig. 342. Two voltameters z z_1 are placed in an iron case, and each of

them has two zinc plates p and p_1, insulated by means of gutta-percha, and immersed in a solution of zinc sulphate. The current decomposes the solution, separating zinc at the negative electrode and sulphuric acid at the positive electrode. The sulphuric acid separated out at the latter dissolves the zinc of the plate. Hence, while the current flows the positive plate becomes continually lighter, and the negative heavier. The effect of the electric current then is

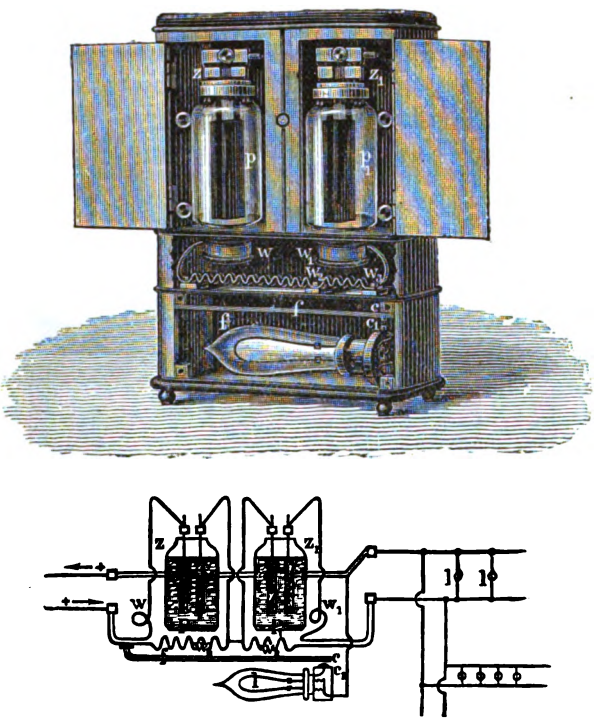


Fig. 342.—Edison's Current Meter.

a transference of the positive to the negative plate. If the voltameter were to be inserted directly into the circuit, one of the zinc plates would be very soon dissolved; to prevent this Edison inserts resistances w_2 and w_3, consisting of German silver shunts, so that only a branch current enters the voltameter. The resistance w_2 is double the resistance w_3, therefore the separated quantity of zinc in one of the voltameters is four times as large as in the other. The one is intended for the monthly measurements, the other serves as check to the former. To render the process of decomposition independent of temperature, two resistance wires w and w_1 are inserted; so that when the temperature rises the resistance in the wire will be increased, but that in the liquid diminished.

By giving a suitable resistance to the wire, the changes of resistance in the wire and liquid may be made to balance each other.

The spring f consists of two different metals, and serves the purpose of causing the contact pins c and c_1 to touch whenever the temperature has been lowered beyond a certain limit, and by this means to insert the lamp l into the circuit. As soon as the desired temperature in the fluids of the voltameter is again obtained, the springs bend upwards, and contact with the lamp is broken.

The apparatus just described is made in two sizes, one for twenty-five and the other for fifty lamps. For central stations Edison uses the larger apparatus,

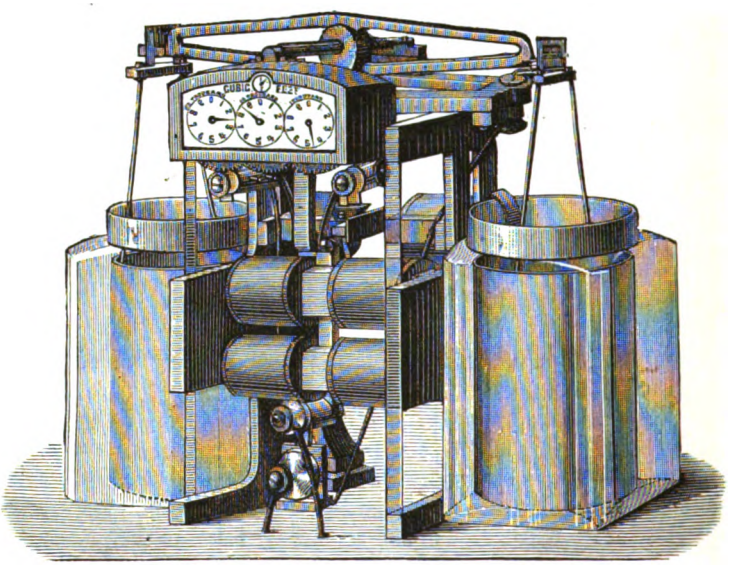


Fig. 343.—Edison's Larger Register.

shown in Fig. 343, which registers automatically. From the two ends of a balance beam coils of sheet copper are suspended so as to form electrodes. They both dip into glass vessels containing copper sulphate. Each cell contains an electrolytic solution, a stationary electrode, and two other electrodes which are movable up and down by the oscillations of the balance arm to which they are attached. Whichever arm of the balance is uppermost carries the kathode, which receives a deposit of metal, while the other is the anode of its cell, and loses metal. The apparatus is inserted into the circuit, so that one of the coils forms the negative electrode ; the current will deposit the copper at this electrode, and as soon as a certain weight is accumulated, the arm of the balance will sink. By means of a simple contrivance the current is now made to flow in the opposite direction, and the separation of the copper to take place at the second spiral. The

acid will dissolve the copper at the first electrode and make it lighter. In this manner the balance beam will oscillate with a velocity depending on the quantity of electricity which passes. The oscillation is transmitted to an apparatus similar to the indicator of a gas-meter, which registers the amount of electricity consumed.

The apparatus shown in Fig. 344 is constructed by Edison on the principle that the velocity of a motor having a given load will be proportional to the strength of the current. If, therefore, the motor be so arranged as to rotate very slowly when a current passes through it, the increase of velocity will be proportional to the increase of the strength of the current. The motor might be inserted by means of its armature coils or the coils of its inducing magnets into the main or a branch circuit. To furnish the load for the motor, paddles may be used moving in a thick fluid. The armature A of the electromagnet M has on its prolonged axis *a* the paddles F, which move in a box K filled with glycerine. The motion is transmitted to the shaft W and also to the pointer Z.

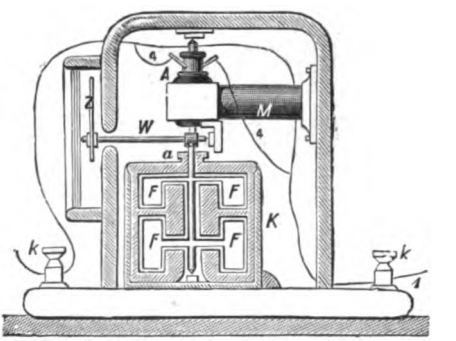


Fig. 344.—Edison's Paddle-wheel Register.

The decomposition and re-uniting of the elements of water by the electric current has also been used by Edison for constructing registering and measuring apparatus.

Ferranti and Thomson also make use of electrolysis for measuring and registering the current; they do not, however, employ the primary current for the decomposition, but an induced one. When this apparatus is used, great care has to be taken to prevent the oxy-hydrogen gases from exploding.

Charles A. Carus-Wilson has constructed a registering apparatus on the principle of electric endosmosis. The apparatus consists of a voltameter, in which the two electrodes are separated from each other by means of a porous partition. The electric current causes the fluid from the anode cell to enter the kathode cell. Both these cells are connected with a glass globe by means of a glass tube. Hence the fluid will then flow through a closed circuit from the anode to the kathode cell, and through the globe back to the anode cell. This motion is transmitted to a register by means of a wheel fastened to the globe. The velocity of the index of the motor depends on the velocity with which the fluid moves, the latter being determined by the strength of the current; hence, the apparatus may be used for measuring the strength of the current.

Siemens and Halske's Energy Meters.—The apparatus constructed by Siemens and Halske measures the product of the difference of potential or

E. M. F., and the strength of the current (Fig. 345). By means of clockwork the disc *a* is made to move with a uniform velocity, and is pressed against another disc *c*; the axis of *c* is fixed to the iron core *e* of the solenoid *f*. The velocity of the disc *c* is greatest when it is pulled nearest the circumference of *a*, and least when nearest the centre of *a*, and consequently is determined by the strength of the solenoid *f*. The disc *b* is connected with the axis of *c*, so

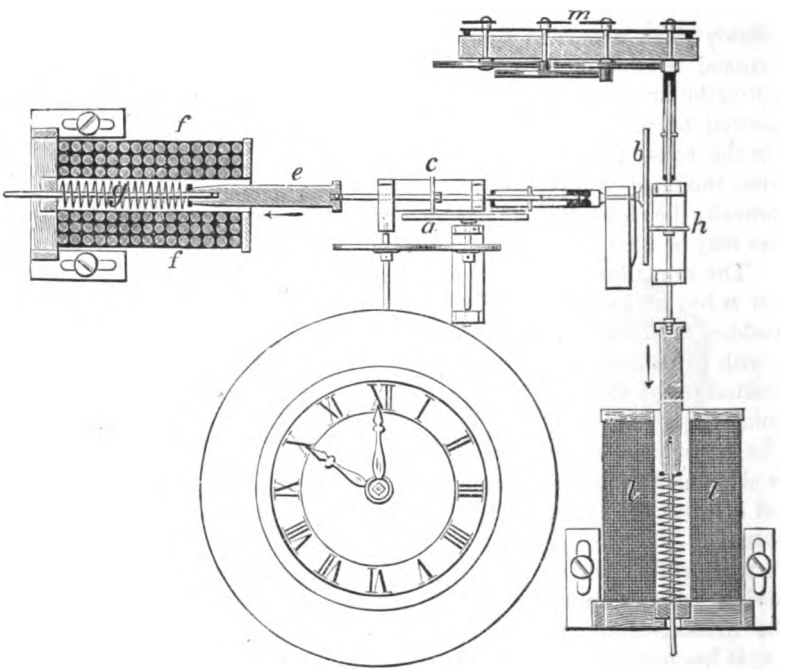


Fig. 345.—Siemens and Halske's Meter.

as to rotate with the same velocity as *c*. The disc *b* transmits its motion to the disc *h*, the axis of which is fastened to the iron core of the solenoid *l*.

The position of the disc *h* upon the disc *b*, and consequently the rate of rotation, must be determined by the force of the solenoid *l*.

But the velocity of the disc *c* is determined by the force of the solenoid *f*, and is transmitted to *h*, and therefore it follows that the resulting velocity of *h* is determined by the product of the forces of the solenoids *f* and *l*. The coils of the solenoid *f* are inserted in the main circuit, and those of *l*, consisting of thin wires, are inserted in a branch circuit which is connected with the main circuit. The force, therefore, which the solenoid *f* exercises upon its iron core is proportional to the strength of current in the main circuit; the force of the

solenoid *l* is a measure of the difference of potential between the points with which the terminals of this solenoid are connected. The product of the forces of the solenoid will therefore be, difference of potential × strength of current, and the velocity of disc *h* may be taken as a measure for this product. The motion of *h* is transmitted to a registering apparatus *m*, which may be graduated as required.

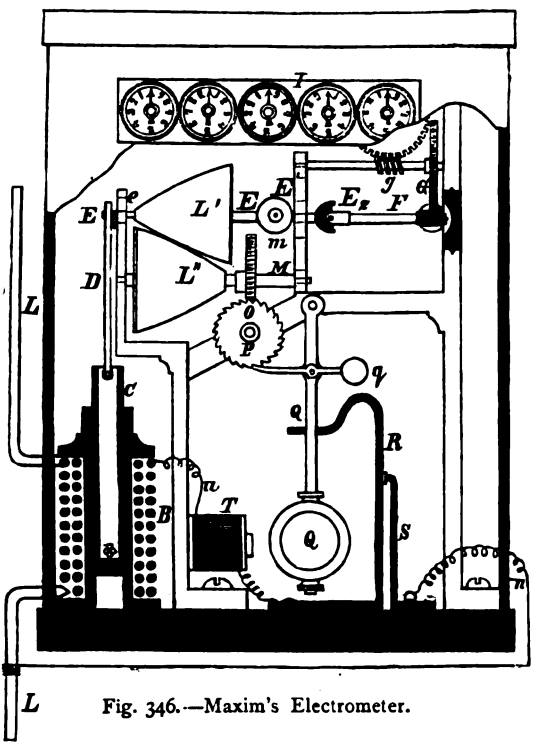


Fig. 346.—Maxim's Electrometer.

Messrs. Siemens and Halske also construct energy meters in which the product of difference of potential by strength of current is measured by means of two coils, one of which is fixed and the other movable, being suspended by a silk fibre and a spiral spring, as in their torsion galvanometer. The instrument represents an electro-dynamo meter, the fixed coil of which is inserted between the points, the electrical energy between which is to be measured. The movable coil of the meter is put in the main circuit. The current in the movable coil will be proportional to the current of the main circuit, and the current in the fixed coil will be proportional to the difference of potential between the two points. It follows that the torsion moment of the former must be proportional to the electric energy (product of strength of current by difference of potential).

Maxim's Electrometer. — Fig. 346 represents an electrometer constructed by Maxim. The solenoid B is inserted in the main circuit L L. *n n* is a branch circuit in which the electro-magnet T is inserted. The latter keeps the pendulum Q Q in constant motion in the following manner, when a current passes through the coils of the electro-magnet: the armature Q of the electro-magnet T is attracted; the pendulum, therefore, will move towards the left, taking with it the spring R, which breaks contact with S; the circuit is thus broken and T is then without current. The pendulum Q falls back again, making contact between R and S, and causing a current again to pass through the electro-magnet. The motion of the pendulum is transmitted to the wheel *m* by means of *q*, O, and a toothed wheel P fastened upon the axis of O, not shown in the figure. The shaft D M of the wheel *m* carries the cone L″, which, when moving, touches the cone L′, causing it to move also. The axis of L′ has a movable weight E_1, and is connected by means of a joint E_2 with the shaft F of the registering apparatus. One end of the axis E is connected with the core *c* of the solenoid B, by means of the rod D. This motion of the iron core causes a lowering and raising of the axis E at *e*, which again causes the cone L′ to touch the cone L″ with more or less surface, and in this way the ratio of the times of rotation of the two is altered as the attracting force of the solenoid B alters. The registering apparatus, therefore, will go faster or slower in proportion to the strength of the current. The apparatus is similar in principle to the dynamometer constructed by Charles A. Carus-Wilson, but differs in the details. Similar apparatus has been constructed by Brush, Swan, etc. etc.

GALVANIC BATTERIES.

Galvanic Batteries.—Cazin says, in his well-known work on "Electric or Galvanic Batteries," a hydro-electric pile or battery is an apparatus consisting of liquid and solid portions, which produces electricity and gives rise to chemical combinations. In dividing the elements into classes we shall follow this author, not because we consider his classification to be the best from a scientific point of view, but because the different classes can be easily grouped by means of the characteristic differences which form the basis of his classification. We may divide all batteries into two large classes: the first comprises all those batteries in which one fluid only is used; the second class comprises all two-fluid batteries. Each of these groups is further subdivided into two classes, of which the one includes all elements in which polarisation occurs; the other includes all those in which polarisation is entirely avoided or considerably reduced. Therefore we distinguish between:

(1) Elements with one fluid and polarisation.

(2) With one fluid, but without polarisation.

(3) With two fluids, the composition of which is not changed by chemical action.

(4) With two fluids that are altered by the chemical action.

ELEMENTS OF ONE FLUID IN WHICH POLARISATION OCCURS.

Volta's Cell.—To this group belongs the voltaic element. It consists of zinc and copper plates arranged alternately, and immersed in salt water or acidulated water. Sulphuric acid diluted with sixteen times its volume of water is generally used. The chemical process is as follows: Zinc, in presence of sulphuric acid, decomposes water into its elements, namely, hydrogen and oxygen. The zinc combines with the oxygen to form zinc oxide, which unites with the sulphuric acid to form zinc sulphate, whilst hydrogen gas escapes at the surface of the copper plate. Negative electricity is produced at the zinc plate and positive electricity at the copper plate, or in other words, there is a difference of potential between the two plates, this potential of the copper being higher than that of the zinc.

We have already pointed out (Part I., page 110) that polarisation takes place in the voltaic element, *i.e.* an E. M. F. is produced which is opposed to the E. M. F. of the element, as the liquid, which consisted originally of diluted sulphuric acid, becomes mixed with zinc sulphate, or is entirely displaced by it, and the copper becomes coated with hydrogen gas. Therefore this element does not give a constant current, and is consequently of little use for practical purposes.

The principal modifications of the voltaic pile in use have been already mentioned, with the exception of one used in medicine, viz. Pulvermacher's chain, represented in Fig. 347. Each element of this battery consists of a piece of wood, about which a copper wire and a zinc wire are wound, but insulated from each other. The four wire ends of each part are bent so as to form loops, by means of which the copper wire of the one pair is connected with the zinc wire of the next, and so on. Vinegar is used as the fluid, the girdle being immersed in it; the wood retains the vinegar, and the battery remains charged even when taken out of the liquid. If magnesium be substituted for zinc, the current is considerably increased, and water may be used instead of vinegar.

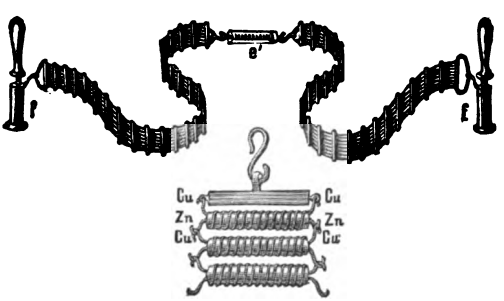


Fig. 347.—Pulvermacher's Chain.

The desire to improve the voltaic pile led to many alterations, the most important of which we will now consider. By using amalgamated zinc instead of commercial zinc only, great improvement was made. Sturgeon, in 1830, seems to have been the first to make practical use of it, although it was known to Kemp in 1828 that amalgamated zinc would not decompose acidulated

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water. It is well known to chemists that pure zinc does not decompose acidulated water when immersed in it, but its production would be too expensive to enable us to use it for galvanic batteries. The zinc generally used is mixed with other metals, and the presence of these impurities causes the formation of a large number of separate elements on its surface. Whenever such a plate of commercial zinc is immersed in acidulated water, a decomposition of the water and solution of zinc will take place, even when the element is not closed, which means a loss of zinc during a period when the battery does not work. Amalgamated zinc behaves like chemically pure zinc.

In order to prevent polarisation, or diminish it as much as possible, other fluids were proposed instead of dilute sulphuric acid. Polarisation, for instance, is considerably diminished by adding a few drops of nitric acid. The hydrogen reduces the acid to ammonia by combining with its nitrogen, and compounds of ammonia are formed which have little or no effect on the resistance and the E. M. F. of the battery. By using copper sulphate to avoid polarisation, the copper is deposited upon the zinc plate, and thus diminishes its surface; and zinc is dissolved when the element is not closed, the effect being due to the formation of minute elements of the copper particles with the zinc.

By using chromic acid, the E. M. F. is increased and polarisation diminished, the O of the acid combining with the H of the water set free. Polarisation is not, however, entirely avoided by this means; and, besides, the acid is too expensive. Fechner (1831) prepared the positive plate by coating that side of the copper plate facing the zinc plate with either cupric chloride or copper sulphate. By using a plate thus prepared, the coating is dissolved by degrees and the rough surface of the copper plate is exposed. The irregularities of the surface of the plate prevent the hydrogen bubbles from adhering to the surface, and thus diminish polarisation. Bagration (1844) used for his elements similarly prepared copper plates and flower-pots filled with earth, which was saturated with a solution of sal-ammoniac. His battery gave a constant but very feeble current.

The next step in the improvement of the voltaic element was to find a substitute for the expensive copper. Carbon was chosen, although by using it the resistance in the element is increased; polarisation is, however, diminished, because hydrogen and zinc salts are not so easily separated at the carbon plate. Helm (Mühlhausen) obtained satisfactory results with an element consisting of carbon cylinders and zinc cylinders in a solution of alum, with sodium chloride added to the liquid to improve the conductivity. Sixteen such elements were employed to supply twenty electric clocks with a current, to obtain uniformity in the system, two elements being refilled every week. Frequent attempts have been made to replace the copper by iron, because by so doing not only would the cost be reduced, but also the polarisation. A modification of the Smee element is shown in Fig. 348, constructed by Tyer. Pieces of zinc are placed at the bottom of the glass vessel, and mercury is poured upon them so as to produce contact. A platinised silver plate, resting with its lead frame upon the

edges of the glass, is arranged as shown in the figure. A mixture of su phuric acid and water in proportion of one to twenty is used. The elements are joined by means of leaden balls which dip into the mercury, and are connected by means of copper wires to the binding screws of the platinised silver plates. Baron Ebner used, instead of a platinised silver plate, a platinised lead plate, which lowered the cost, but lowered also the E. M. F. To avoid having the plates coated with hydrogen, Maistre constructed an element in which the electrode is kept constantly in motion, either by the hand or by clock-work. When the plates become coated with hydrogen they are lifted out of the liquid, and the hydrogen is thus allowed to escape. According to Maistre's statement, the current becomes fairly constant, and its intensity is greater than that of a Daniell's element.

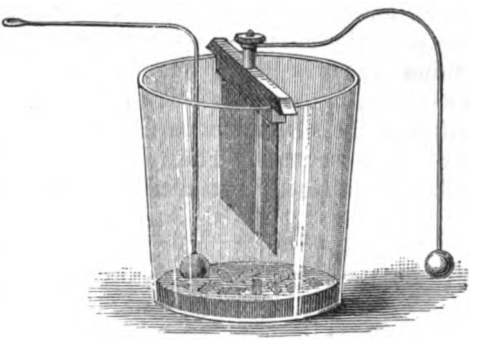

Fig. 348.—Tyer's Form of the Smee Element.

ELEMENTS OF ONE FLUID WITHOUT POLARISATION.

De la Rue's Battery.—If we allow the generation of hydrogen in elements of one fluid, it is impossible to avoid polarisation, although it may be reduced by using the different means to detach the gas from the electrode. Better results, however, are obtained when care is taken that the hydrogen at the moment of its liberation is made to combine chemically with some other substance. The more perfect this combination, the more completely will polarisation be avoided. Both solids and fluids are used to combine with the hydrogen. The solids used to prevent polarisation are certain salts of lead and mercury. Becquerel constructed (1846) a battery, using lead sulphate; and De la Rue was the first to propose lead peroxide for avoiding polarisation. Warren de la Rue and Müller (1868) used an element suggested by Marié Davy (1860), as a practical and convenient form for causing depolarisation by means of silver chloride. In the original form the element consisted of an unamalgamated zinc rod, and a silver wire surrounded by silver chloride, which were both immersed in a solution of ordinary salt. The silver chloride became reduced to silver, the chlorine uniting with the zinc at the same time to form zinc chloride. The reduced silver is a spongy mass, which allows the liquid to penetrate to the interior of the silver chloride cylinder. Owing to this, the element remains active until the whole of the silver chloride is reduced. The element has been modified as follows: The form of the outer vessel is cylindrical, and it is filled with ammonia solution, into which an unamalgamated zinc rod and a cylinder of chloride of silver dip. The latter is

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covered with parchment. The silver strip fused into the chloride of silver cylinder pierces the parchment several times, to keep it in position on the one hand, and to facilitate the starting of the element on the other. The vessel is closed by a plug of paraffin. The current which the new element furnishes is very feeble at first, owing to the small surface of the silver electrode; but after the element has been in use for a short time, the reduced silver of the silver chloride forms a larger surface, and the current soon attains its normal strength. The results which Warren de la Rue obtained are as follows: his battery generated in the voltameter

On the 29th June,	1875,	per minute,	1 cubic metre of gas.		
,, 4th July,	,,	,,	1·4	,,	
,, 27th Oct.,	,,	,,	1·4	,,	
,, 15th March,	1876,	,,	1·45	,,	
,, 8th April,	,,	,,	1·41	,,	

Warren de la Rue constructed batteries containing as many as 11,000 elements, arranged in sets of ten cells contained in vulcanite supports, as shown

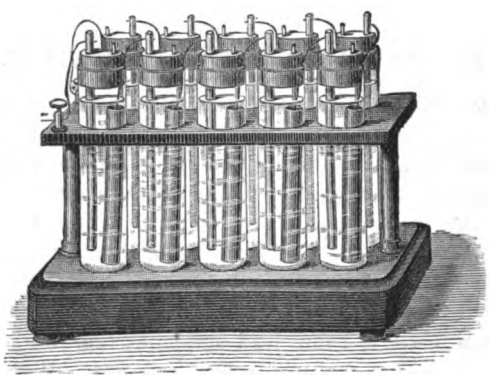


Fig. 349.—Warren de la Rue's Battery.

Fig. 350.—The Gaiffe Element.

in Fig. 349. The E. M. F. of a chloride of silver element of the old form, with ordinary salt, is 0·97; and the E. M. F. of the modified form with ammonia salt, 1·03 of that of a Daniell's cell; and the resistance = 4·2 ohms.

Pincus constructed a silver chloride battery for medical purposes, independent of Warren de la Rue. Gaiffe made the vessel of his battery, also intended for medical purposes, of ebonite; a lid is screwed to the top of the vessel so as to make it air-tight. The two electrodes are fastened to the lid, as shown in Fig. 350, and consist of a zinc rod and a molten silver chloride cylinder. The latter, forming the negative electrode, is placed in a copper vessel covered with linen. The electrodes are kept in position by the india-rubber rings I K.

and the pieces of caoutchouc *r i*, which are placed between them. The element must not be upset, because by wetting the lid it becomes short-circuited. Gaiffe prevented this by putting several layers of filter paper, wetted with a solution of zinc chloride, between the electrodes instead of the liquid.

Of the solid bodies which have been used for the prevention of polarisation, manganese dioxide has been most extensively used. De la Rue recommended its use, but the suggestion has led as yet to no satisfactory results.

Leclanché's Cell.—Leclanché improved upon the manganese peroxide element, and Fig. 351 represents one of the forms which he gave it. The four-sided form is preferred to the round, because in this manner, when a number are placed together to form a battery, the space is more completely utilised. The glass vessel has a porous cell of cylindrical shape, the diameter of which is such as almost to fill the space in the glass vessel. The zinc rod is placed as shown in the figure. This arrangement is to prevent the evaporation of the fluid as much as possible. The porous cell has a carbon block surrounded by a mixture of small pieces of carbon and manganese dioxide, the top being covered by means of pitch, leaving one small hole so as to allow air to pass through. The glass vessel is half filled with a strong solution of ammonia chloride (sal-ammoniac). A leaden cap carrying a binding screw is attached to the top of each block of carbon in order to obtain a good contact. A zinc rod is better than a zinc cylinder, because the carbon electrode has, in regard to the size of its surface, considerable ascendency; which has much to do with the prevention of polarisation. The zinc rod ought neither to be cast nor wrought, but drawn out; the reason for this lies in the different properties of the three kinds. Through casting, zinc becomes crystalline, brittle, and not homogeneous in structure. Owing to the porous condition, the zinc surface would unnecessarily be increased, which would hasten the solution of the zinc; besides cast zinc is never pure, but contains small quantities of many other metals, such as lead, etc. It has been mentioned that these metals would form minute elements with the zinc as soon as it is dipped into a fluid, and thus considerably aid the useless solution of the zinc. Wrought zinc would have nearly the same properties, although zinc, when wrought, has to be purer to stand the process; however, the best material is zinc which has been drawn out. Leclanché uses amalgamated zinc rods, so as to obtain a uniform wearing-out of the electrode. If the wear be not uniform, rough places would be produced which would facilitate the formation of crystals, and would not only increase the resistance of the elements, but also diminish the surface of the electrode. The negative electrode, too, requires attention

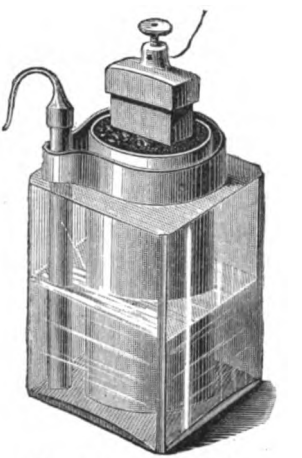


Fig. 351.—Leclanché's Element.

with regard to certain conditions. It has been mentioned that for filling the porous pot every manganese ore cannot be used, but only that modification known under the name of pyrolusite (peroxide of manganese), which alone possesses the conductivity required. Both the carbon and pyrolusite ought to be rough-grained, but to powder them would increase the resistance. The experiments by Beetz showed that powdered carbon under any conditions gave unsatisfactory results. Polarisation is avoided best by using big grains of carbon and powdered pyrolusite, because then the hydrogen meets the pyrolusite at every point polarised, which is not always the case when large grains are used. Greater E. M. F. is, however, obtained by using grained pyrolusite. The solution of ammonia chloride is concentrated, because by its use the resistance is diminished, and a concentrated solution is better able to take up the salts produced during the use of the element, and to prevent the separation of the salts at the electrodes, and consequent weakening of the current. The change that takes place is as follows: The zinc, sal-ammoniac, and pyrolusite are changed into zinc chloride, water, and ammonia, and an oxide of manganese richer in oxygen. Zn, $2NH_4Cl$, $2MnO_2$ are changed into $ZnCl_2$, $H_2O + 2NH_3$, Mn_2O_3. Three different sizes of this form of the element are constructed, regarding which Cazin has arranged the following table:

	Porous Pot.		Separation of Copper in the Voltameter.	Re[illegible]
	Diameter.	Height.		
1st size.	6 centimetres.	11 centimetres.	40 gr.	9 to 1[illegible]
2nd ,,	6 ,,	15 ,,	60 to 70 ,,	5 to 6
3rd ,,	8 ,,	15 ,,	100 to 125 ,,	about 4

The Leclanché element consumes very little zinc, as zinc is only dissolved when the element is in use. The behaviour of the element when exposed to cold is important. According to experiments made by Lartigue, the resistance of the element is not very much altered, even when the temperature is considerably lowered, whilst the resistance in a Daniell's element is from 8·35 at + 10° to 12·58 at 0°; at − 4° the resistance rises to 14, at − 6° the fluid becomes thick, and at − 20° the resistance rises to 200 units.*

By using a diaphragm the resistance in the element is considerably increased, and is further increased when the grains of the carbon and pyrolusite mixture are not pressed close together, because the fluid conducts worse than the mixture. Leclanché tried to avoid this by altering the carbon electrode. In order to obtain a compact mass, gum is added to the mixture, which is heated to 100° C. under a pressure of 300 atmospheres. Solid cylinders are produced in this manner, consisting of 40 parts pyrolusite, 52 parts carbon, 5 parts gum, and 3 parts potassium bisulphate. The latter facilitates the solution of the zinc salts that enter the pores. To the upper part of the cylinder

* W. Ph. Hauck, "Elektrotechnische Bibliothek," iv.

a zinc knob is fastened. The zinc electrode consists of a zinc rod held in position and separated from the carbon by means of a piece of wood and caoutchouc rings, as shown in Fig. 352. By this modification, however, no better results were obtained, the inner resistance being increased considerably. Leclanché, therefore, constructed blocks of the above mixture, which were fastened to a carbon plate by means of caoutchouc rings, shown in Fig. 353. The alteration of the resistance may be compensated for by using several plates.

Tyer's Element.—The pyrolusite element by Tyer, shown in Fig. 354, consists of a porcelain vessel, which is divided by a perforated plate of the same material in two unequal portions. The smaller is taken up by the carbon plate

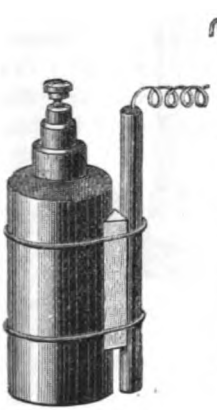


Fig. 352.

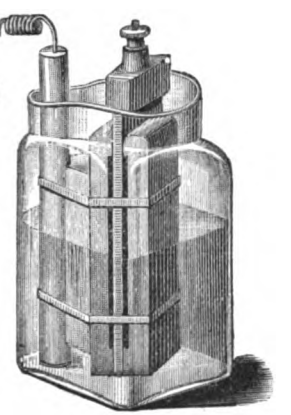


Fig. 353.

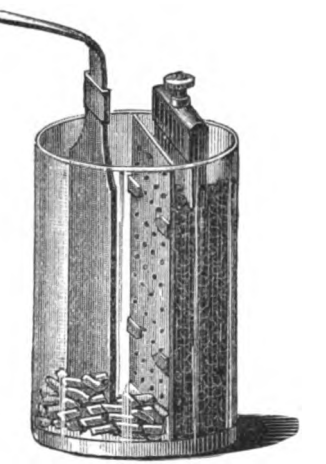


Fig. 354.—The Tyer Element.

and pyrolusite mixture; the larger has the zinc plate and ammonia salts. This element is, however, quickly polarised. The permanent element by Marcus belongs to this group of elements. The Leclanché element has been further modified by Clark and Muirhead, Binder, Gaiffe, Lister, and others.

Modifications by Lalande and Chaperon.—The Leclanché element will not answer at all when a constant current is required, but it does very well indeed where a current is required for a short time only, as, for instance, in sending signals, ringing bells, etc., especially as the element may be used for several months. At the International Electrical Exhibition, Vienna, 1883, an element in which depolarisation was brought about by means of copper oxide attracted the attention of electricians. The inventors of it are De Lalande and Chaperon (the description and drawings are taken from *La Lumière Électrique*, Vol. IX.). The cylindrically-shaped glass vessel V (Fig. 355) has a box A made of sheet iron, which contains the copper oxide B. To the box an insulated copper wire C is fastened. The zinc electrode D has the form of a

spiral, and is fastened to the screw F. The straight end of the zinc which does not reach the liquid has an india-rubber coating G. The inducing fluid consists of potassium oxide dissolved in water, 100 parts of the fluid containing 30 to 40 parts by weight of potassium oxide. To avoid the handling of potash the required quantity of potassium oxide is placed in the copper oxide box, and covered

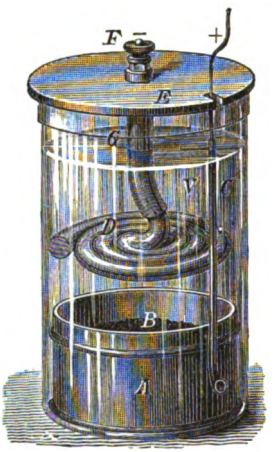


Fig. 355.—The Chaperon Element.

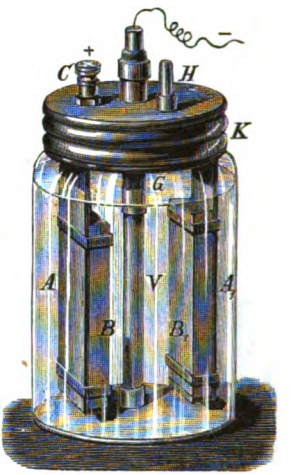


Fig. 356.—The Lalande Element.

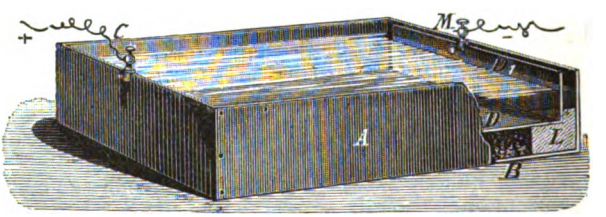


Fig. 357.—Lalande's Trough Element.

up by means of a lid; when the element is to be used, water is added first, and then the necessary amount of copper oxide. In Fig. 356 the glass vessel V is tightly closed by means of a copper lid and india-rubber band K. To the lid are screwed two sheet-iron plates A A_1, to which the copper oxide blocks B B_1 are fastened by means of india-rubber rings. C represents the positive pole. A tube surrounded by an india-rubber coating G is situated in the centre of the vessel, and in this tube the zinc rod is placed. H is a tube having an india-rubber valve, which only opens when the pressure of the gases generated in the element becomes too great.

Since vessels consisting of copper and iron are not acted upon by the fluid,

large surfaces may be given to such elements. The vessel A (Fig. 357) consists of sheet iron, forming the positive pole of the battery; it is 40 centimetres long, 20 centimetres broad, and 10 centimetres high. The bottom of it is covered with a layer of oxidised copper. At the four corners porcelain insulators L are placed to carry the horizontal zinc plate $D D_1$, the side D_1 being bent at right angles. The iron vessel is three-parts filled with potash solution. The screw C is fastened to the iron vessel, the screw M to the bent zinc plate. To prevent evaporation and the combination of carbon dioxide from the air with the potash, a lid is placed upon the vessel, or a thin layer of petroleum is poured over the surface of the fluid. According to experiments made by E. Hospitalier, and published in *L'Électricien*, 1883, the Lalande element is superior to the Daniell element in using less zinc, and superior to the Leclanché element in being more constant. For every gramme of zinc nearly three grammes of potassium oxide and 1·25 grammes of oxidised copper are used. The resistance of this element during use diminishes, because the oxidised copper is replaced by the better-conducting metallic copper. The element has, however, only a moderate E. M. F., namely, 0·98 volts. A slight modification of the Lalande element is the plate element,* which has the advantage over the Lalande element, that when not in use the metallic copper becomes re-oxidised. When the element is not closed by an outer circuit the carbon and copper in the liquid represent a closed element, which gives off hydrogen at the carbon, and oxygen at the copper; the former escapes, the latter oxidises the copper. Whenever the outer circuit is broken, the generation of gas commences, and at the same time the copper loses its bright colour.

Fig. 358. — The Grenet or Flask Element.

Chromic acid, which parts easily with a large proportion of its oxygen, is another of the fluids which, more or less, prevent polarisation. Warrington first used chromic acid with electrodes of platinum and zinc, forming a kind of Grove's cell in which the nitric acid was replaced by chromic acid. For carbon-zinc elements, Bunsen, Laeson, and Poggendorff have also used chromic acid, or mixtures which produce it. For this purpose potassium bichromate, sulphuric acid, and water are used, when potassium sulphate is formed and chromic acid set free. The sulphuric acid not only binds the potassium and sets free the chromic acid, but also dissolves the zinc, therefore if too much sulphuric acid be added, zinc sulphate will also be present in the element.

The Bichromate Bottle Element.—Grenet's bichromate element (Fig. 358) has bichromate of potash added to sulphuric acid. The cell is usually

* From the vulcanised lid of the vessel an insulated copper wire is fastened to the bottom of a carbon cylinder (closed at the bottom). The inside of the carbon cylinder is filled with oxidised copper.

of a flask or bottle shape. The zinc plate z is in the middle, and a pair of carbon plates K K, one on each side of the zinc, are joined at the top and constitute the positive pole. The zinc plate z is attached to a rod *a*, by which it can be lifted out of the solution when the element is not in use. This is necessary, as the solution acts on the zinc even when the circuit is broken.

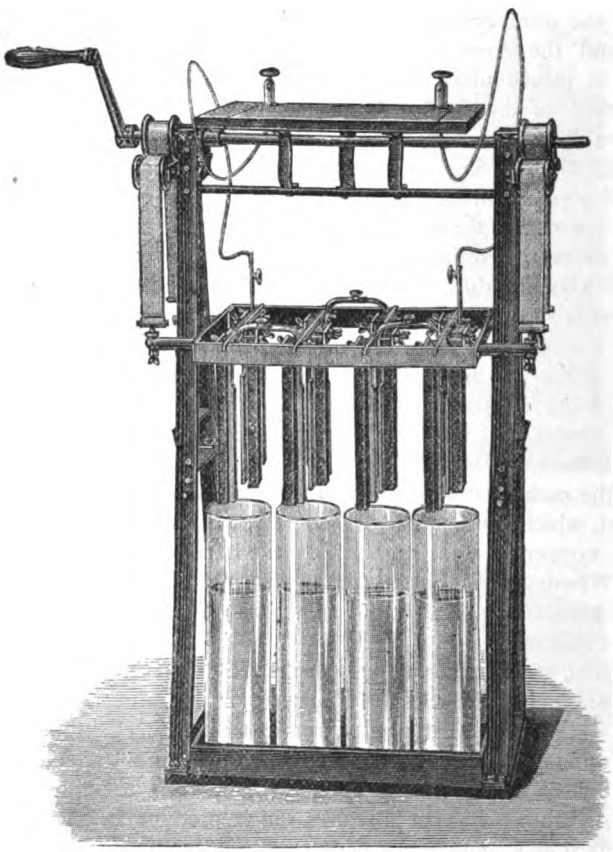


Fig. 359.—A Bunsen Chromate Battery.

Bunsen's Chromate Battery. — Bunsen's battery, belonging to this class, is shown in Figs. 359 and 360. The details of the connections of the plates are shown in Fig. 360. The catches on the two sides rest on the rectangular frame, so that when the frame is lowered by the winch handle, the zinc drops into one cylindrical cell, and the carbons into the next. The E. M. F. is at first quite equal to 2·3 Daniells, but is not constant.

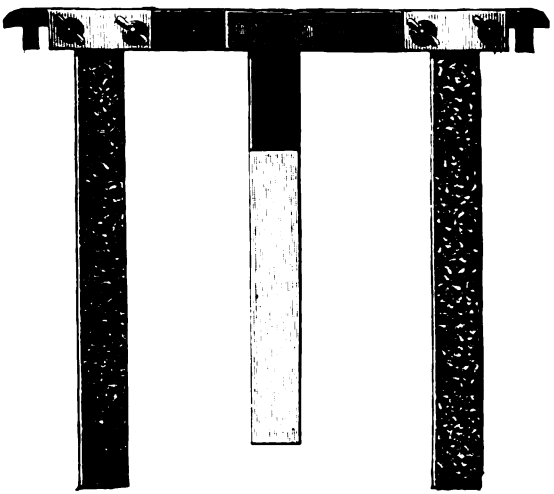


Fig. 300.—Connections of Bunsen Battery.

Hauck's Chromate Battery.—Fig. 361 shows Hauck's battery. The connection of the plates with the lid M M is seen in the right-hand figure. The

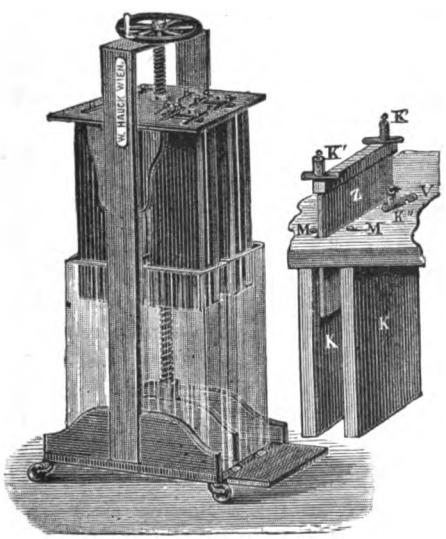


Fig. 361.—The Hauck Element.

clamps K K' K'' are to connect the carbon of one cell with the zinc of the next. The zinc plates Z may be raised through the lid, and the whole lid with its

carbon plates K K, as well as the zinc, can be lifted out by means of the screw and hand-wheel seen at the top of the figure.

Trouvé's Cell.—Trouvé's elements, shown in Figs. 362 and 363, give a very powerful current for a short time The lower diagram shows how the plates are connected with each other. There are fourteen plates connected as follows: Three carbon plates are joined to each other by means of the metal rod A, thus forming one carbon plate of large surface; the zinc plates joined to the metal rod C represent also one large zinc plate. To the metal rod B four zinc plates and four carbon plates are fastened, representing respectively a large carbon and a large zinc plate. The zinc and carbon plates of B form one element, and the plates of C and A another element. The two elements are thus joined in series. The poles of this two-celled battery are at A and C. The zinc and carbon plates are placed vertically (Fig. 362), and to prevent them from touching each other, the carbon plates have india-rubber caps at both ends. The plates are kept together by a frame, which is lifted by means of the handle A. T is a leaden pipe, by means of which air can be forced through the apparatus. These elements give a very powerful current at first, but the strength very soon decreases.

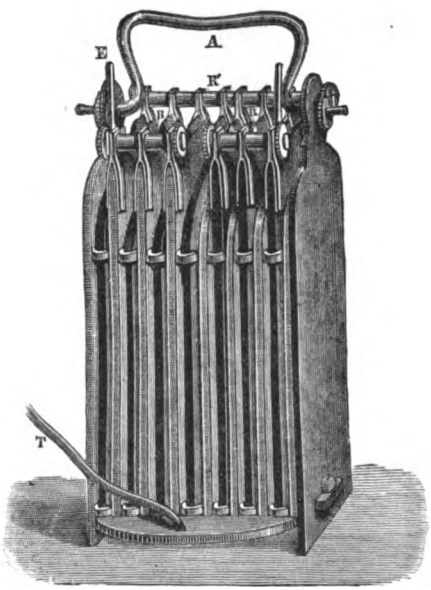


Fig. 362.—The Trouvé Element.

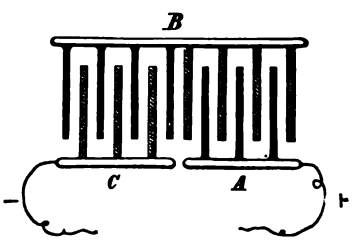


Fig. 363.—Plan.

Trouvé also constructed elements for medical purposes, etc., with hermetically sealed lids, as represented in Fig. 364. This cell consists of an ebonite box, closed at both ends. The amalgamated zinc rod is connected with a knob outside (the negative knob), while the carbon cylinder is connected with the positive knob. The box is only half-filled with the acid liquid, and contact is made by shaking the box. As sulphuric acid is not convenient for domestic purposes, it is avoided as much as possible, being in this case replaced by a mixture of one-third of potassium bichromate and two-thirds of potassium bisulphate.

Zinc-Carbon Elements with Salt Solutions.—Not only are combinations of solids and liquids used for diminishing polarisation, but gases also, as for instance the oxygen of the air, may effect the same purpose. Fig. 365 represents an element frequently used in Switzerland. F is a carbon cylinder fourteen centimetres high and nine centimetres in outer diameter, acting as the negative electrode. G is an amalgamated zinc strip, acting as the positive electrode. These elements are therefore described as zinc-carbon elements with salt solution.

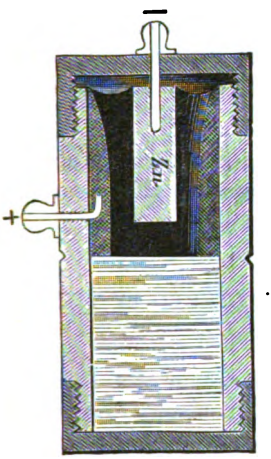


Fig. 364.—Closed Trouvé Element.

Fig. 365.—Zinc Salt Water Carbon Element.

Fig. 366.—The Maiche Element.

The Maiche Element.—Fig. 366 represents the zinc-carbon element with a salt of ammonia, by L. Maiche. It is contained in a cylindrical glass vessel having an ebonite lid; a porous vessel having holes in the side is fastened to the lid. In the porous cell is placed platinised carbon, forming the negative electrode. A platinum wire leads from it to a binding screw on the lid. Through the centre of the lid an ebonite tube passes, having at its end a porcelain basin containing mercury and pieces of zinc, which form the positive electrode. A second platinum wire connects the basin containing the mercury, through the ebonite tube, with the remaining binding screw. The vessel holds about 1·5 litres of the liquid, which consists either of 250 grammes of ammonia salt, or 140 to 150 grammes of sodium bisulphate, mixed with about 5 to 10 per cent. of sulphuric acid. The E. M. F. of the element is equal to 1·25 volts, and the resistance is half an ohm. In comparison with other elements this is a cheap arrangement, because depolarisation here is caused by the air, or rather by the oxygen contained in the air. To allow the oxygen to reach the

carbon more easily, the porous vessel dips into the fluid to a depth of about two centimetres. The current soon falls off in consequence of the increased generation of hydrogen, which consumes the oxygen stored in the carbon. By taking the zinc electrode away from the carbon electrode, the deposition of crystals on the carbon is prevented.

Two-Fluid Cells.—Volta was the first who observed that a combination of two liquids and a metal produced a galvanic current. Becquerel examined more minutely the behaviour of the different liquids. To obtain a constant current, not only is it necessary to adopt some means of depolarising the electrodes, but it is necessary also to devise a means of keeping the resistance constant. Now the resistance varies with the chemical changes of the liquid, and also with the degree of concentration of the chemically unaltered fluid. On account of these differences Cazin divides the elements with two liquids into two groups:

1. Those fluids which have their composition unaltered by the chemical action.
2. Those which undergo chemical change, and consequently offer a varying resistance to the current.

ELEMENTS OF TWO LIQUIDS WHICH ARE NOT ALTERED BY THE CHEMICAL ACTION.

Daniell's Element.—On page 111 we gave a description of a Daniell's element in its original shape, and shall, therefore, find it necessary to consider here only those modifications of the Daniell's cell which are likely to be of practical interest. In the form represented in Fig. 89, a porous earthenware vessel is substituted for the membrane from the jugular vein of an ox. If we examine the porous vessel of an element that has been in use for some time, we find that figures representing the foliage and branches of trees, or little crystals, cover its surface. These are crystals of copper. The copper separated out in this manner sometimes goes through the porous cell, and is then in direct contact with the zinc, forming minute elements, which, producing only local action, decompose copper sulphate, but do no useful work. The deposition of copper on the surface of the diaphragm is sometimes caused by the zinc residue which coats the cell. This sediment consists of iron, lead, copper, carbon, etc., which dissolve but slowly in the dilute sulphuric acid, if indeed they dissolve at all.

To prevent this the porous pot is sometimes replaced by parchment. If the element is arranged so that the zinc together with the sulphuric acid are inside the porous pot, the separation of copper may be prevented by having the zinc placed in the middle of the pot, and the bottom of the diaphragm coated with wax. The zinc residue now remains at the bottom, and the solution of copper bisulphate cannot pass through it. Kramer prevents the separation of copper in the diaphragm by having the copper electrode divided into

two cylinders. One of these K (Fig. 367) is placed in the diaphragm *b*, which is filled with a solution of copper sulphate, and is together with it placed within a second diaphragm containing dilute sulphuric acid.

The zinc cylinder is placed outside the second diaphragm. This second diaphragm and zinc cylinder are omitted in the figure.

Provided the element has sufficient copper sulphate, it may be used for months without requiring attention.

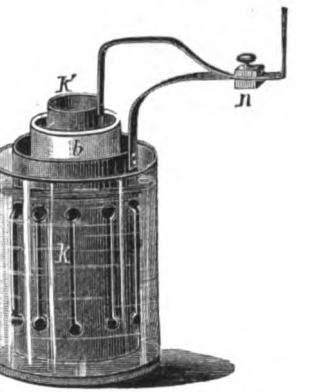


Fig. 367.—The Kramer Element.

The Trough Battery.—Two modifications of the Daniell element are used in the English telegraph service; one is the Fuller trough element, the other the Muirhead battery. The trough element, shown in Fig. 368, consists of a rectangular box divided into cells by slate partitions. Each of these cells is again divided into two parts by means of a porous porcelain plate. One of these divisions has a solution of copper sulphate, and a copper plate, and the other portion has either water or a very dilute solution of zinc sulphate and a zinc plate. A zinc plate and a copper plate are joined by means of a copper strip, which is bent so as to allow every two plates to hang from the slate partitions. The zinc plate of the last cell and the copper plate of the first cell

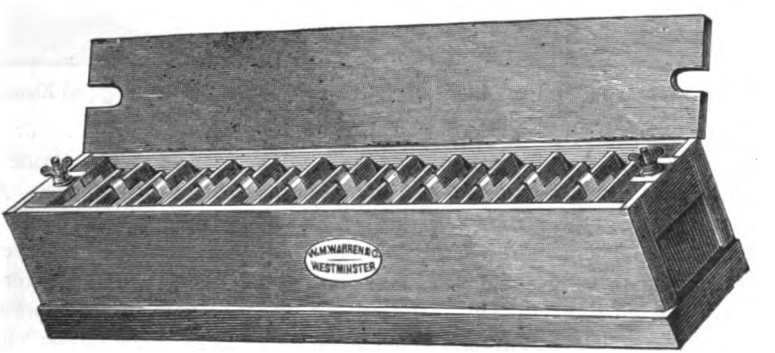


Fig. 368.—The Trough Battery

form the poles. By placing crystals of copper sulphate in the respective cells so as to have a sufficiently concentrated solution, the battery may be a whole month in use without attention. This battery is usually furnished with cast zinc plates, which, for reasons we have considered, are not recommended. It is also difficult to obtain air-tight divisions by the combination of slate and wood.

As the Daniell element remains constant for a considerable period, and causes no unpleasant fumes, it has been used for lighting purposes, and to remove the resistance caused by the diaphragm several devices have been adopted. Carré replaced the earthenware cell by parchment, and for the production of the electric light joined in series sixty elements, which furnished a tolerably constant and powerful current.

Siemens and Halske made their Daniell's element of the form shown in Fig. 369. At the bottom of the cylindrical vessel A, a copper spiral or plate is placed, and from the centre of this plate a copper wire leads upwards and forms the positive electrode. Over the plate comes a porous clay vessel, indicated by the dotted lines in the figure, and having a glass tube fastened to it. The space over the clay vessel is filled up to *e* by a prepared paste,

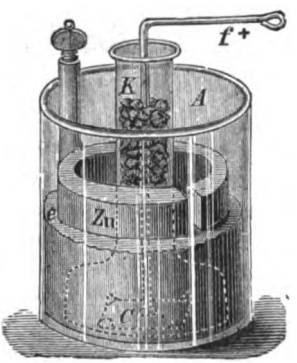


Fig. 369.—Siemens and Halske's Element.

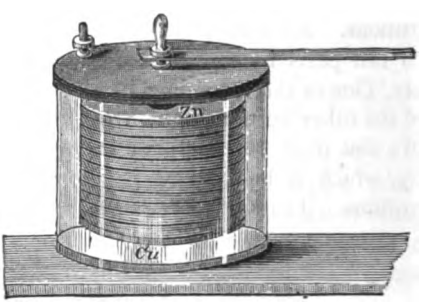


Fig. 370.—Trouvé's Blotting-pad Element.

consisting of a mixture of paper paste and sulphuric acid. The space within the clay vessel and glass tube is taken up by crystals of copper sulphate. A piece of linen is placed over the paper mass, and upon this the zinc ring *z n* is laid. From the zinc a brass rod with screw passes upwards. The element is charged by pouring acidulated water into the tube K, and the outer vessel A. The diaphragm, thickened by means of the paper mass, presents a high resistance, but this does not matter very much for telegraphic purposes, as the outer circuit also has a high resistance. The current remains constant when the fluid surroundiug the zinc is removed every fortnight and replaced. The piece of linen must also be cleaned at similar intervals. When the element has been in use for some time, copper is found to have separated out at the diaphragm and in the paper mass, nor does this element entirely prevent the copper sulphate from reaching the zinc.

Trouvé's Blotting-pad Element.—Trouvé tried to prevent the consumption of zinc in elements when not in use by an arrangement shown in Fig. 370. This form of the Trouvé element consists of a zinc and a copper

plate, between which a great many blotting-paper discs are placed. The one half of the blotting-paper nearest the copper plate is soaked in a solution of copper sulphate, and then allowed to dry. A copper wire having a gutta-percha coating is soldered to the copper plate, going through the centre of the blotting-paper and zinc, and being fastened to the lid of the vessel as shown in the figure. The second wire represents the zinc pole of the element. When the element is to be used, water is poured upon the paper discs until drops are seen to appear at the edges, when they are pressed together. The element is then placed in the glass vessel and is ready for use. The copper sulphate is gradually consumed, whilst zinc sulphate is produced. When the whole of the copper sulphate is used up, which will not happen for some months, the element has to be recharged. Useless consumption may be avoided by exposing the element to a draught of air after use.

This form of battery is especially recommended for military and medical purposes.

Minotto's Element.—The disadvantages of diaphragms in elements have caused many attempts to be made to avoid them altogether. Minotto, for instance, substituted sand for the porous cell. Minotto's element consists of an earthenware vessel, one half of which is filled with crystals of copper sulphate. A copper wire covered with gutta-percha is soldered to a copper plate, which is embedded in the crystals of copper sulphate and forms the positive pole. Over the crystals a layer of sand is placed; non-absorbent sand, such as quartz, being used. Upon this layer of sand the zinc plate is laid. The wire attached to the zinc plate ought to be coiled so as to allow the zinc plate to be lowered as the crystals are consumed. Water is usually poured on the top of the zinc. When the element has been in use for some time the zinc plate ought to be cleaned occasionally. The resistance of this element is greater than that of a Daniell cell, but might be diminished by having the copper plate higher, or even by placing it on the top of the crystals.

The electromotive force of the Minotto element is nearly that of a Daniell element, and remains constant for months. Compared with the latter element, it uses less zinc and copper sulphate, and requires very little attention, the occasional cleaning of the zinc plate and replacing of the evaporated water excepted. P. Secchi, on examining a Minotto element that had been in use for a considerable length of time, found that the solid matter formed from the copper and zinc sulphate crystals had the copper intermingled in exactly the same manner as copper crystallises out in natural ores. It may be assumed, therefore, that the crystallisation of the copper in a metallic vein in the earth is due to a slow chemical process, similar to that observed in the Minotto element.

Barley (1855) took out a patent for an element in which the diaphragm was entirely avoided, and the fluids separated by their own specific weights, but this element has been little used for practical purposes.

Meidinger's Element.—Meidinger's element, which is extensively used in Germany, is represented in Figs. 371 and 372. The outer vessel A is drawn in at C, as shown in the figure. The zinc cylinder Z rests with its lower edge upon *b*, and has the wire C connected with it. A second smaller vessel is placed inside A; and sheet copper or sheet lead, forming the second electrode, is placed inside the second vessel, the connecting wire *g f* being well insulated. The tube *h*, which is open at the end, contains crystals of copper sulphate.

To charge the element the outer vessel A is filled with water or a solution of bitter salts, to diminish resistance. The crystals dissolve and a solution of

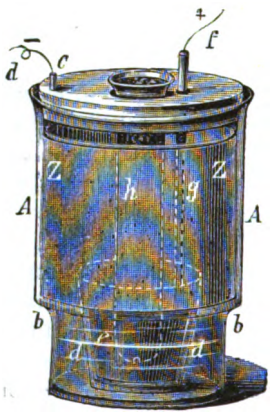


Fig. 371.

Fig. 372.

Meidinger's Element.

copper sulphate surrounds the copper or lead electrode. Copper sulphate, having a greater specific gravity, falls to the bottom of the vessel, whilst the lighter salt solution remains in the upper part of the vessel surrounding the zinc cylinder. When the element is employed for telegraphic purposes, the crystals of copper sulphate are soon consumed, and must be replaced. The battery, therefore, requires special attention, and on this account Meidinger arranged his element as shown in Fig. 372. In the balloon element the tube holding the crystals is replaced by a glass globe, which serves as a cover to the vessel. The E. M. F. of this element is about the same as that of a Daniell cell, but the resistance in a Meidinger element is considerably lessened by leaving out the diaphragm.

Krüger again modified the Meidinger element, and obtained a cheaper form with a smaller resistance. A further modification of Meidinger's element is the Kohlfürst element, represented in Fig. 373. The vessel A is covered

at the top by an iron lid D. To the lower side of the lid the zinc z is fastened, and to the upper side the binding screw *x*. A leaden plate, placed nearly at the bottom, serves as the second electrode, and is connected with the insulated copper wire *f*. The portion *b b* is covered with crystals of copper sulphate, at the top of which a perforated earthenware plate is laid. The liquid is poured down the funnel L, and consists of either a solution of zinc sulphate or bitter salts. The following tables are taken from a report published by the managers of the Buschtetwarder railways, and show the saving by employing the Kohlfürst element instead of the open Meidinger or Krüger elements:

Year.	In use.		The expenses of the Batteries come to:					
			Total.		Per Electro-magnet.		Per Galvanic Element.	
	Elements.	Electro-magnets.	fl.	kr.	fl.	kr.	fl.	kr.
1873	2604	744	6702	88	·9	00·9	2	57·4
1874	2582	1114	7246	95	6	50	2	80·6
1875	2556	1135	6754	61	5	95	2	60·4
1876	2723	1237	6288	41	5	08	2	30·9
1877	2871	1249	3957	36	3	17	1	37·8
1878	2726	1235	2892	—	2	34	1	06·0
1879	2630	1168	2382	65	2	00·4	—	90·5
1880	2637	1165	2164	42	1	85·7	—	85·0

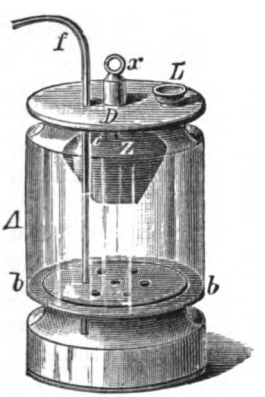


Fig. 373.—The Kohlfürst Element.

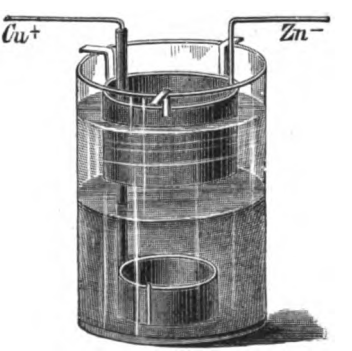


Fig. 374.—The Callaud Element.

The Callaud Element.—The Meidinger element was reduced to its simplest form by Callaud in 1861, whose arrangement is represented in Fig. 374. At the bottom of the vessel is placed a cylinder or spiral of sheet copper, and from it an insulated copper wire leads out of the vessel. The zinc cylinder

is suspended, as shown in the figure. It is filled with a solution of copper sulphate to about three centimetres from the zinc cylinder. Water, or a solution of zinc sulphate, is poured on to the top of the copper sulphate solution.

The Callaud element is frequently used in France and the United States. Its dimensions are as follows: The glass is 20 centimetres high, and has a diameter of about 13 centimetres. The copper sheet is 3 centimetres high, and has a surface of one square decimetre. The zinc sheet is 7 centimetres wide, and has a radius of 5 centimetres. Every three months the zinc is cleaned, and at the same time 200 to 300 grammes of copper sulphate are added. To

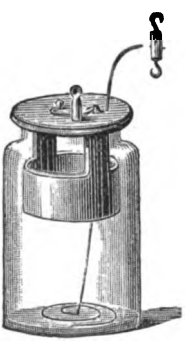


Fig. 375.—Modified Callaud.

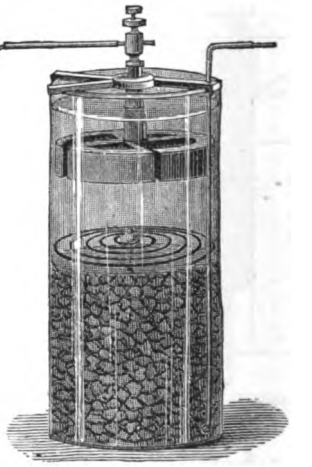


Fig. 376.—The Lockwood Element.

prevent the increase of resistance, a portion of the solution of zinc sulphate is removed, and is replaced by water.

It has been found convenient to pour the zinc sulphate solution into the vessel first, until it nearly reaches the zinc cylinder, and then by means of a syphon to allow the copper sulphate to replace the solution of zinc sulphate.

From observations made by different persons during several years, it has been calculated that an element costs on an average 32 kreutzers (or 6½d.) per annum.

The following results were obtained by Cailleret regarding its resistance:

Jan.	26, 1876.	Resistance,	32·5	units.
,,	29,	,,	25	,,
Feb.	4,	,,	17·5	,,
,,	12,	,,	11·5	,,
,,	16,	,,	10·5	,,
,,	25,	,,	9·25	,,

A modification of the Callaud element is shown in Fig. 375. Fig. 376 represents the form which Lockwood gave it. The zinc electrode is suspended from the vessel in the manner shown in the figure. The vessel is 28 centimetres high by 14 wide. One half of it is filled with crystals of copper sulphate. The copper electrode consists of two spirals, of which the one lies at the bottom of the vessel, the other at the top of the crystals. The wire which comes out of the glass to form the positive pole is a continuation of the two spirals. The liquid used is a solution of zinc sulphate. Evaporation is diminished by a layer of oil.

Reynier's Daniell.—The form which Reynier has given to the Daniell element is shown in Fig. 377. Sheet copper, which has the shape represented in Fig. 378, is placed in the vessel. Next comes a cell of parchment containing

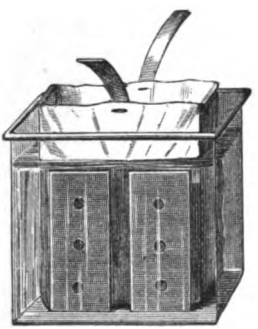


Fig. 377.—The Cell.

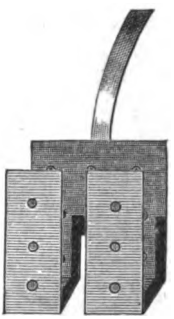


Fig. 378.—The Copper.

The Reynier Element.

sheet zinc, bent as in the figure. Solution of copper sulphate is poured into the glass vessel, and sodium hydrate into the parchment cell. By substituting sodium hydrate for sulphuric acid, diffusion of the copper sulphate crystals is prevented, and also the E. M. F. is increased from 1·3 to 1·5 volts. The dissolving of zinc when the battery is not in use is also prevented by means of the arrangement. A further modification is described on page 409.

ELEMENTS WITH TWO FLUIDS WHICH UNDERGO CHEMICAL CHANGE.

Grove's Element.—Grove was the first to construct an element with two fluids, in which nitric acid formed the depolarising substance (1839). The form usually given to the Grove element has been described on page 112. The expensive platinum metal has been replaced by plates of porcelain, coated with a layer of platinum (burnt into it); such elements, however, have a considerable resistance, owing to the thin layer of platinum; moreover, it is difficult to attach the pole wire.

Bunsen's Element.—The Bunsen element, in which carbon is substituted for platinum, has also been described in Part I. (page 112). Fig. 379 represents the form which is given to the element when it is intended to be joined up with other elements to form a battery. While care ought to be taken that all the metal parts are bright, emery paper ought not to be used, as particles of it may adhere and diminish contact. The best plan is to file the different parts that are used in forming contacts. Careful amalgamation of the zincs is also important, but the methods of effecting the amalgamation will be considered later. The great objection to the Bunsen element is the generation of noxious fumes by it. In spite of this, however, it is very frequently used on account of its constancy, its high E. M. F. (about 1·9 volts), and small resistance. The Bunsen element is less constant than the Daniell element, owing to the chemical changes the fluids undergo. To diminish the resistance and volume of the acids required, and also to save space, the Bunsen as well as the Grove element has been constructed of plates arranged in rectangular vessels. As the zinc and carbon plates may be laid very close to each other, the resistance may be diminished to about 0·060 ohm. Rousse substituted a lead cylinder for the zinc cylinder, and Maiche an iron cylinder, which he placed in water acidulated with nitric acid (1 part in 100). This arrangement causes greater constancy and diminishes the evolution of gas, but reduces the E. M. F. to 0·8 of a Bunsen element. Several inventors have successfully replaced the platinum by iron.

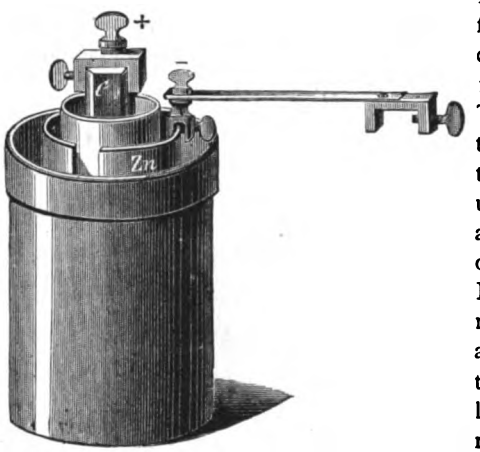


Fig. 379.—A Bunsen Element.

Schönbein made use of cast-iron pots and a liquid consisting of two parts of concentrated nitric acid and one part of sulphuric acid, with an earthenware pot containing diluted sulphuric acid, the zinc being placed in the latter liquid. As sulphuric acid takes away the elements of water from nitric acid, it prevents the latter from becoming too diluted, which is important on account of the action of dilute acid on the iron. By using concentrated nitric acid, iron becomes what is called "passive." In this condition alone can it be utilised in a galvanic element; when the acid is diluted beyond a certain limit, the iron is acted upon During the Exhibition at Paris an element constructed by Howell, represented in Fig. 380, was exhibited. In the cylindrically-shaped earthenware vessel A the cell B is placed, containing the diaphragm C and the zinc rod Z. The carbon block K consists of a mixture of pyrolusite,* carbon, and manganese sulphate.

* Pyrolusite is a native peroxide of manganese

This mixture is well pressed and covered with a layer of bituminous carbon to allow the generated gases to escape. For the same reason the cover has several holes. The earthenware cell contains a solution of ammonium sulphate (2·5 per cent.) and a little mercury, so that the zinc shall always be well amalgamated. The fluid in the outer vessel consists of diluted sulphuric acid. The resistance of the element is said to be from 5 to 6 ohms, and its E. M. F. $2\frac{1}{4}$ volts.

Buff's Element.—To produce a cheap and odourless element, Buff constructed an iron chloride element, in which the zinc is placed in an earthenware cell containing diluted sulphuric acid, whilst the carbon is immersed in ferric chloride having the consistency of treacle.

The element gives better results when hydrochloric acid is added to the ferric chloride, and ordinary salt used instead of the diluted sulphuric acid. Depolarisation in this element is not very complete, and the current is weakened by the production of non-conducting deposits at the electrodes.

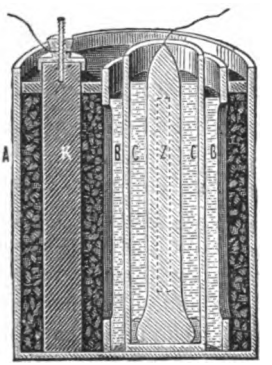


Fig. 380.—The Howell Element.

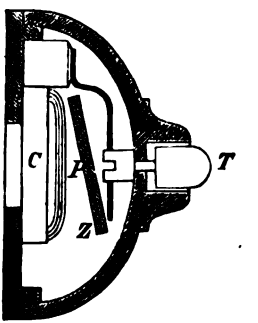


Fig. 381.—The Scrivanow Element.

Scrivanow's Dry Element.—In the Scrivanow element fluids are avoided altogether. The dry element consists of a carbon and zinc plate, and a depolarising substance, which is a kind of amalgam compounded of ammonium mercuric compound (10 parts), sodium chloride (3 parts), and silver chloride (0·25 part), made into a paste by means of a diluted solution of zinc chloride. This paste is laid on the carbon plate and covered with paraffin to the thickness of two millimetres. On this are placed several layers of Swedish filtering paper which have been soaked in a solution consisting of zinc chloride and sodium chloride. The edges of the paper discs are coated with paraffin, by means of which they are fastened to the carbon. This element may be arranged in the form of a key, as used for electric house bells; such a key is shown in Fig. 381. C is the carbon, Z the zinc, P the layer of filtering paper; and between P and C the depolarising substance is placed. By pressing T, the zinc is pressed against the layer of paper soaked in the solution, and the element is closed.

The Marié Davy Element.—Marié Davy replaced the sulphuric acid in the Bunsen element by proto-sulphate of mercury. Thirty-eight of these elements supplied a telegraph line day and night with currents equal in strength to that of 60 Daniell elements. A record of the durability of these batteries shows that the Marié Davy elements could be used for five months and twenty-three days, whilst the Daniell element lasted only two months and twenty-three days. A point in favour of the mercury elements is that little mercury need be wasted, as it can be easily reconverted into the proto-sulphate. On the other hand, the high price, and the fact that the mercury salts are very poisonous, are against its use.

Sulphur may be classed with the depolarising agents, sulphuretted hydrogen of course being generated in the element. Savary allows the zinc to dip into a solution of ordinary salt, and adds to the salt water, which surrounds the carbon in the diaphragm, powdered sulphur; he also strengthens the carbon by a few turns of copper wire. The element is said to be very constant, and in its action to resemble a Daniell element.

The Fuller Element. – The Fuller element, which has been used by the English Telegraph Department since 1871, and of which there are about 20,000 elements in use, is a chromic acid element, represented in Fig. 382. z is the zinc electrode, which is in the shape of a rod flattened at the end or attached to a pyramidal foot. This rod is placed in a porous vessel, and in order to have it well amalgamated, about 30 grammes (or from 1 to 2 ounces) of mercury are placed in the earthenware pot. The upper part of the rod is covered with wax. The carbon plate *a* is outside the diaphragm, and is 15 centimetres long by 5 centimetres wide. The porous pot containing the zinc rod is placed in a glass vessel, which is filled to within two inches of the top with a solution of 90 grammes (3 ounces) of bichromate of potash in one part of sulphuric acid and nine parts of water. Water only is poured on the mercury in the inner cell. This element produces twice the electromotive force of a Daniell element, with a smaller resistance under equal conditions. The addition of the mercury is the essential feature of the battery, and to it the disappearance of the main objections against the old bichromate form is chiefly due. The zinc plate is, in this way, kept permanently amalgamated so long as it lasts; and not only is the internal resistance of the battery largely diminished, but its constancy is to a great extent insured. The action (after the battery is charged, and the elements connected) commences almost immediately, and reaches a maximum in the course of a few hours. On an ordinary working circuit, no extra crystals will be required for a period of six months, after the battery is once set up; nor, indeed, so long as the solution remains of an orange colour. Only when it begins to assume a blue tint need crystals be added to it.

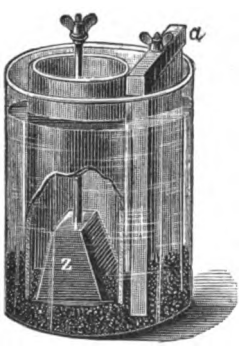


Fig. 382.—Fuller's Patent Mercury Bichromate Element.

The electro-motive force of the combination is equal to about two volts; the internal resistance, by varying the thickness of the porous vessel and the strength of the solution, may be made to vary from half an ohm up to four ohms, according to the work which the battery is called upon to perform.

In point of cost, this battery compares very favourably with others which are at present employed in England. Taking, for instance, the Daniell, and assuming that both are employed on a hard-worked wire (say, joined up in one of the railway block-signal circuits), the statistics of the cost of each have been found to be as follows:—

Daniell Battery.

Prime cost of a ten-cell trough fitted complete	£1	2	4
Sulphate of copper for six months ...	1	1	8
Complete renewal at the end of six months	0	14	10

Fuller's Mercury Bichromate Battery.

Prime cost of a three-cell battery (equivalent to a ten-cell Daniell)	£0	15	0
Bichromate of potash and sulphuric acid for six months	0	3	7
New zincs and mercury at the end of six months	0	2	8

Generally speaking, this mercury bichromate battery will be found far more economical, and, with few exceptions, as reliable as the Daniell. It is well adapted for medical and experimental purposes, such as the working of induction coils, firing of fuses, heating of platinum wire, feeding incandescent lamps, and the like, combining, as it does, at a much smaller cost, the high E. M. F. of the Grove with the convenience in handling of the Daniell.

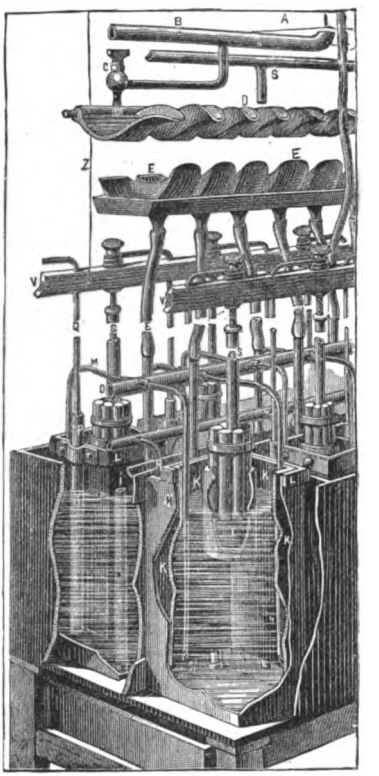


Fig. 383.—The Grenet-Jarriant Battery.

Batteries for Lighting.—To avoid the danger of fire attendant on the use of steam machinery, the *Comptoir d'Escomte* in Paris was supplied with a current for lighting the place by a battery. The battery employed was Grenet and Jarriant's (*see* Fig. 383). The following account of this battery is taken from *La Lumière Électrique:* "Each element consists of an ebonite cubical vessel, having a tube *i* fastened to the bottom, so that the acid can be made to flow off whenever it has reached a certain height in the element. Four carbon plates K are arranged parallel to the sides of the vessel to form the positive electrode, and are connected by means of the lead armature L. The negative electrode consists of several zinc cylinders, which are placed with their lower ends in a box containing mer-

cury. An india-rubber ring presses their upper ends against the metal rod S. The mercury causes good contact amongst the zincs, and at the same time secures their thorough *amalgamation*. Acid is supplied by means of the tube E; air is forced through the horizontal tube D and its vertical branches M. A second system of tubes is intended to allow the rinsing out of the battery after use. The battery has no diaphragm, and the zinc and carbon dip in the same acid. As the acid would dissolve the zinc when the battery is not in use, a contrivance is provided to lift the zincs out of the fluids. Each battery consists of forty-eight elements arranged in two rows and joined up for tension. (*See* Fig. 384.) All the

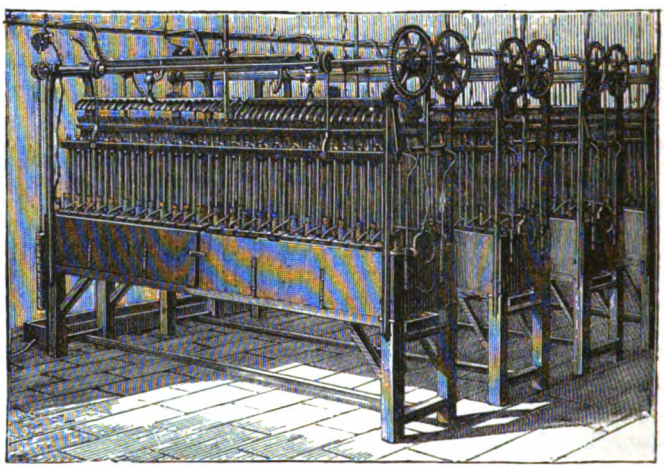


Fig. 384.—The Grenet-Jarriant Battery.

zinc rods S are fastened to the horizontal frame V, and may by means of it be lifted out or lowered. In order that the elements may be joined in series, the metal rod Q is connected with the top end of the rod S. Q dips into the tube P containing mercury, which is fastened to the lead armature L of the carbons. With this arrangement the carbon of one element remains connected with the zinc of the next. The acid flows through B and C into the basins D, which are so arranged that when they contain a certain quantity of acid, say one litre, they are made to discharge it into the tubes E, which have funnels at the tops. The exhausted acid is conducted away by two tubes I. Great care must be taken to have the supply and discharge of the acid well regulated, as well as the flow of air through the apparatus. Each battery has an E. M, F. of 82 volts by 24 amperes. Grenet and Jarriant, instead of potassium, use sodium bichromate in the proportion of one part bichromate to three parts sulphuric acid and ten parts water. When fresh acid is used, each battery requires 20 litres per hour, and of acid used once 30 litres per hour, and used twice 40 litres, and used

three times 60 to 80 litres. Sixty batteries, each of forty-eight elements, are used in the *Comptoir d'Escomte*, each battery supplying with current one arc lamp, or eight to ten incandescent lamps." From an economical point of view, this system of lighting is not to be recommended, as the battery consumes zinc and chromic acid substances, which are comparatively expensive. Grenet and Jarriant expect to be able to reduce the expenses by having the compound of chromiun regenerated. The process will be as follows: The fluid used, consisting chiefly of sodium sulphates, chromium, and zinc, is treated with calcium carbonate, so as to neutralise any sulphuric acid present by forming calcium sulphate. Zinc and chromium are precipitated as zinc carbonate and chromic oxide. The liquid, which consists of sodium sulphate, is withdrawn from the precipitate and allowed to crystallise. To the precipitate sulphuric acid is added to convert the zinc carbonate into zinc sulphate, which is separated from the fluid, and also allowed to crystallise. The remaining precipitate, consisting of chromoxide (protoxide of chromium), and calcium sulphate, is fused with sodium nitrate, and when the fused mass is well washed the residue is sodium chromate.

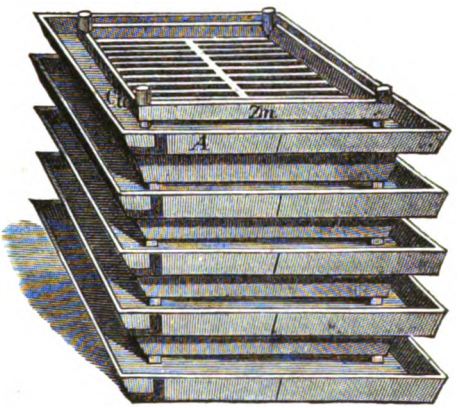


Fig. 385.—The Thomson Pile.

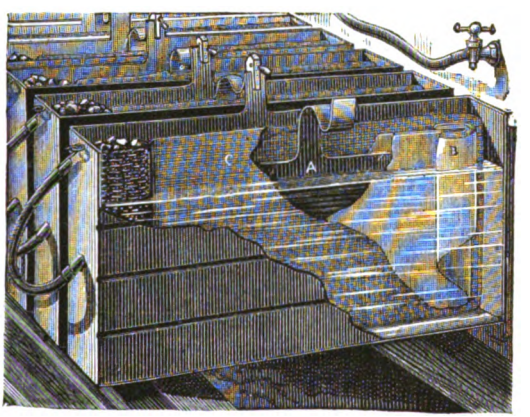


Fig. 386.—The New Reynier Battery.

The Daniell element, on account of its constancy, would be of great value for lighting purposes if its resistance were less; to increase the strength of the current by diminishing the resistance was the object aimed at in the construction of the Thomson pile and the new Reynier battery. The resistance in the Thomson pile (Fig. 385) is diminished by using parchment instead of earthenware cells. Each element consists of a wooden trough A, the bottom of which is covered

with copper, or rather with lead upon which copper is deposited. The zinc plate *z n* rests upon four wooden blocks. Solution of copper sulphate is poured into the trough; the zinc plates are covered with parchment, so that each zinc plate has a cell of parchment; into this water or a solution of zinc sulphate is poured. In arranging the elements in batteries, care has to be taken that they are placed horizontally so as to allow the fluid to spread evenly. The several elements are connected with each other by means of lead strips, which lead from the coating of one trough to the zinc of the next. The parchment may even be left out altogether, the two fluids being arranged in layers as in the Callaud element. The battery does not possess a very high E. M. F.; its resistance, however, is very slight, and the current is very constant, provided the zinc sulphate solution be removed from time to time and replaced by water.

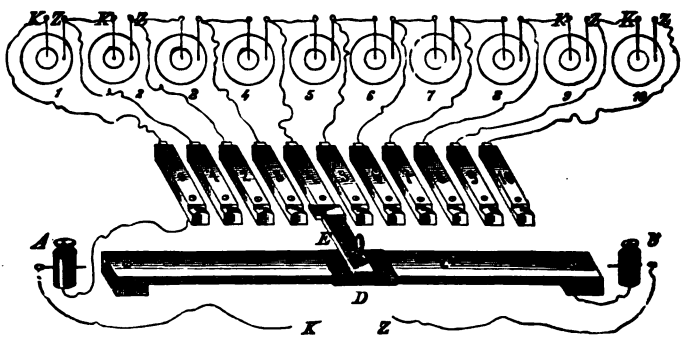


Fig. 387.—Apparatus for Coupling Elements.

Reynier (*see* p. 403) still further modified the Daniell element in the manner shown in Fig 386. The copper electrode has the form of a rectangular trough 22 centimetres high, 5 centimetres wide, and 40 centimetres long. The zinc plate A, which is shorter by 10 to 12 centimetres than the copper electrode, is wrapped up in parchment B. At the short end of each zinc a basket is placed to hold the crystals of copper sulphate. Tubes at the end of each element carry off the fluid. The elements are joined by means of short metal strips, which are held together by clamps as shown in the figure. The copper sulphate solution (to which Reynier added calcium chlorate, sodium chloride, ammonia salts, etc., to diminish resistance) enters the parchment cell, where it is decomposed and thus furnishes the sulphuric acid for the zinc. The zinc sulphate diffuses through the walls of the cell and collects in the copper vessel. Every twenty-four hours 1 litre of fluid per element is replaced by water. In April, 1882, Reynier had 500 such elements, 68 of which he used for charging secondary elements used for lighting purposes; the work done by these sixty-eight elements in eight hours was equivalent to one horse-power, at an outlay of sixteen francs

For lighting purposes these elements are more expensive than gas, but cheaper than candles.

Medical Batteries.—Batteries for medical purposes should supply a constant continuous current, and should admit of the elements being joined and used in any desired order. Then the inactive elements should consume no material; and finally all noxious fumes should be avoided.

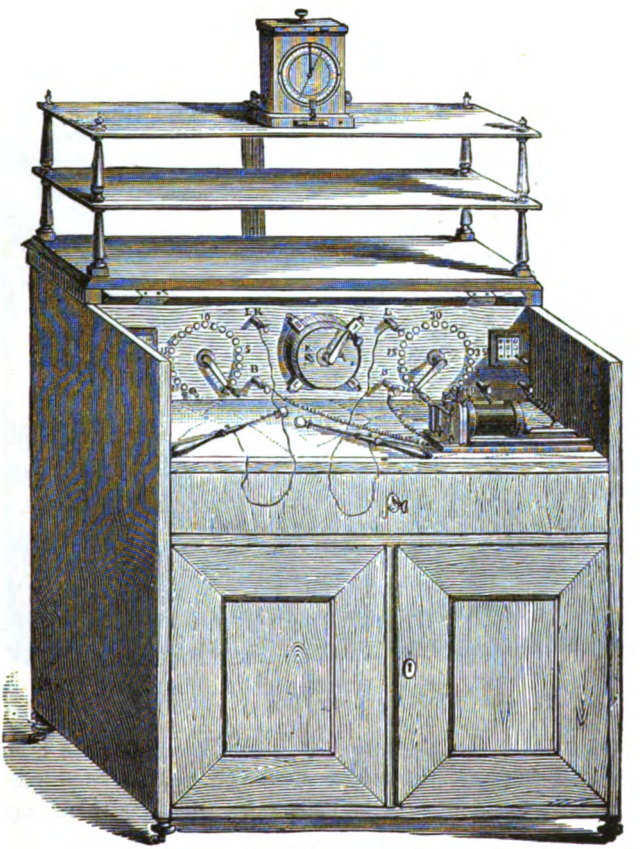


Fig. 388.—Mayer and Wolf's Battery.

Before we proceed to the description of the batteries themselves, we will describe an apparatus by means of which any number of elements may be inserted and removed from the circuit: such an apparatus is shown in Fig. 387. The elements are joined in series, and from each connecting wire another wire leads to the metal strips o to 10. The clamp D is movable along the metal bar C. The binding screw A is connected with the metal strip o, and

the binding screw B with C. By moving D the elements may be inserted and put out of circuit.

Fig. 388 represents a stationary battery, as constructed by Mayer and Wolf, of Vienna; it consists of forty to sixty Siemens elements, which are arranged upon two shelves in a more or less elegant case, which may represent pieces of furniture, such as writing-tables, etc. The battery is associated with a galvanometer, commutator, and induction apparatus. Compared with the Siemens-Remak apparatus made by Krüger and Hirchmann, of Berlin, this battery

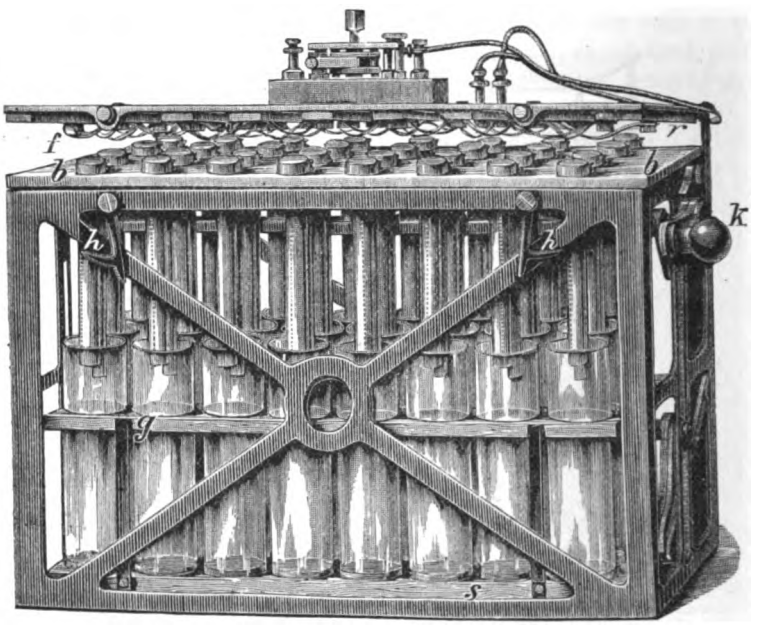


Fig. 389.—Chromate Battery of Heller.

has the advantage that the elements can easily be filled and cleaned without being obliged to unscrew the wires, etc. To prevent one portion of the elements being worn out sooner than the other, they are so arranged that one half of them is used alternately and then the other.

Fig. 389 represents a potassium chromate battery constructed by F. Heller in Nürnberg. Heller aims at making the connections as simple as possible, so as to make it easy to replace the worn-out zincs, etc. The carbons and zincs are simply fixed into a hole of the board *b b*, which rests upon an iron frame. They are joined by means of the springs *f*, which are screwed to the frame *r*. When in use the frame *r* is held down by means of the brass pins *h h*. The glass vessels, which are arranged in the frame *g s*, are lifted to the required height.

A movable potassium chromate battery is shown in Fig. 390; it has been devised by Dr. Spamer and made by R. Galle, Berlin. Carbons and zincs dip into the same fluid, consisting of potassium bichromate, water, sulphuric acid, and mercury sulphate. Three rows of cells consisting of gutta-percha, placed in a drawer, as shown in the figure, contain the fluid. The zincs and carbons belonging to these three rows are attached to three frames, each frame having ten carbons and ten zincs, pointed at their ends, so as to allow the acid to

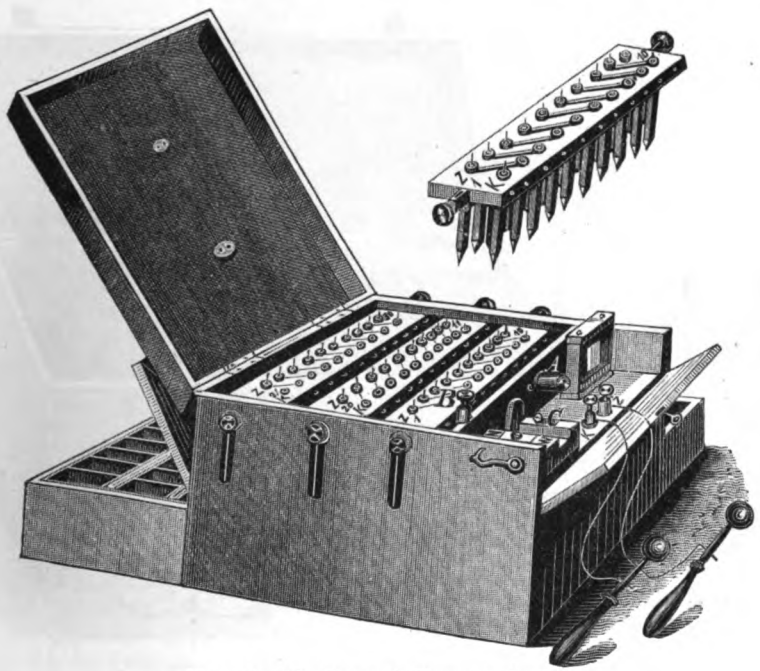


Fig. 390.—Dr. Spamer's Chromate Battery.

run off more easily. They are coated with a varnish that will resist the acid. Each of these frames can be moved up and down by means of the screws outside the case shown in the figure. Only those frames are lowered into the acid that belong to the elements which are to be used. Vertical metal pins are fixed on all the zincs, and on the first and the last carbon, and by means of these pins any number of elements may be inserted in the circuit from one up to thirty.

In the front drawer are placed the galvanometer, the commutator C, the clamps for the electrodes K Z, etc. About ten cubic centimetres of liquid are required for each cell. After use the frames are slowly lifted and left for some minutes. A cover of gutta-percha is placed over the three rows of cells.

Leiter's Battery.—Leiter's movable manganese ore battery is said to be cheap, to give a sufficiently strong and constant current, and to be easily managed.

One of the elements is shown in Fig. 391. The cell B B is made of gutta-percha, and contains a gutta-percha cylinder G Z, which holds the zinc rod. K is the carbon block; the remaining space is filled with manganese ore (manganese dioxide) and pieces of carbon. A platinum wire P connects the carbon

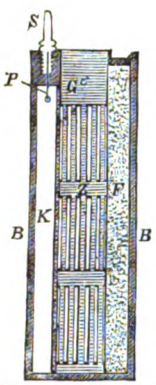


Fig. 391.—Leiter's Element.

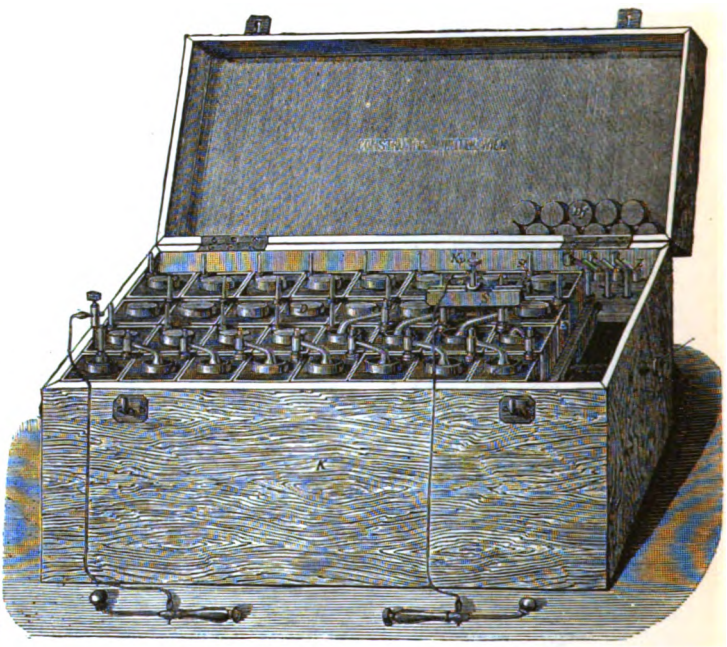


Fig. 392.—Leiter's Battery.

with the zinc piece S, which represents one of the poles of the element. A solution of sal-ammoniac is used. The manganese ore and carbon pieces are separated from each other by a layer of asphalte. A number of elements joined up to form a battery are shown in Fig. 392.

Galvano-Caustic Apparatus.—We shall give a description of one more battery which is of great value in a particular branch of medical science, viz. in cauterising by electricity. By using for this purpose a heated platinum wire loop, bleeding is almost entirely prevented, and parts most difficult to reach can be operated on, as the heat is more local.

Formerly a red-hot iron had to be introduced into the part to be cauterised, but now the platinum wire is inserted while cold, and is made hot when wanted for operation by simply making contact.

Much has been done to advance this branch of medical science by A. Middeldorpf. It will be seen that as the outer circuit of these batteries is a platinum loop which has only small resistance, it is advantageous to have the inner

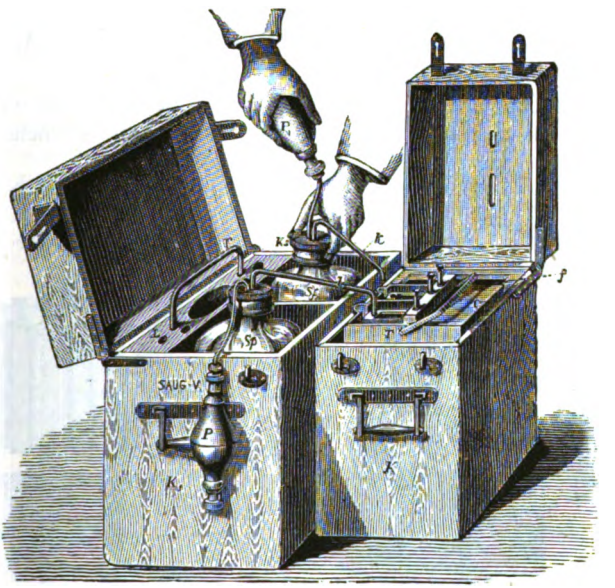


Fig. 393.—Galvano-Caustic Apparatus.

resistance of the battery also only slight. Hence the battery used has large plates and few elements, that is to say, the elements are joined up for quantity.

An apparatus constructed by Leiter for the purpose is shown in Fig. 393. In its essential parts it is a modified Bunsen battery in two boxes. The box K contains the battery, and the other box K_1 the two acids (sulphuric and nitric). The battery vessel T consists of gutta-percha, and is divided into two portions. In each of these a flat earthenware cell is placed to hold the carbon plate and nitric acid. Outside this diaphragm come the zinc plate and diluted sulphuric acid. The elements are covered by means of a gutta-percha lid, shown in Fig. 394. The pole-clamps of the battery are screwed to the lid. When only one element is required clamps 1 and 2 are used, when both elements are required clamps 1 and 3 are used. The acid *Sf* is being forced through the bent glass tube *k* by means

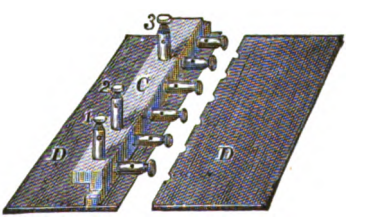


Fig. 394.—The Battery Lid.

of the india-rubber balls P and P_1. The acid is removed from the cells by exhausting the acid bottles; the longer end of the bent glass tube will then have to dip into the cell.

Batteries for Blasting.—Batteries intended for firing blasting charges for military purposes and engineering have to fulfil certain conditions, which have been described at length by Dr. F. Wächter in "Die Anwendung des Elektricität für militärische Zwecke."

The French engineering corps make use of a potassium chromate battery, which is represented in Fig. 395. As many of the elements as may be

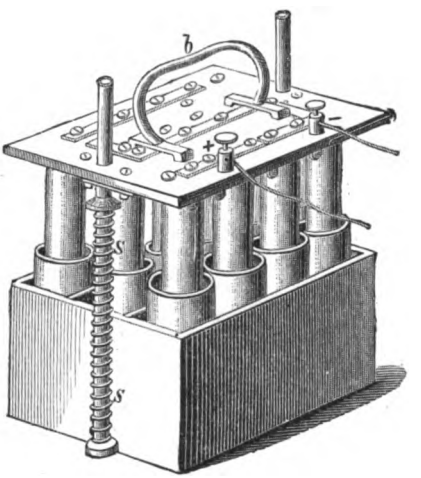


Fig. 395.—Battery for Blasting.

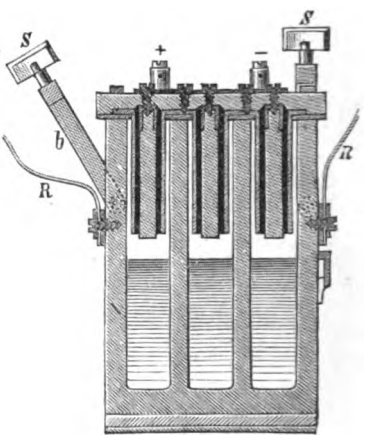


Fig. 396.—Battery for Blasting.

required are placed in a rectangular box. The zinc cylinders surround the carbon blocks, and both are fixed to the board, which is capable of sliding up and down the iron rods fastened to the box. The spring s s forces the board upwards, and by doing so lifts the electrodes out of the liquids. Metal strips screwed to the board connect the elements in series, and also connect the series with the + and the − clamps of the battery. By means of the handle *b* the electrodes can be pushed into the vessels, and at the same time the circuit closed.

This battery does well enough when stationary, but does not answer well for field service. For this purpose the form used is that represented in Fig. 396. The carbons and zincs are fastened to the end of a perfectly air-tight box, closed by means of the screw s on the hinge *b*, acting on an air-tight lid. The potassium chromate solution fills only one-half of the box. To charge the battery it is placed horizontally, so as to allow the liquid to come into contact with the electrodes.

The battery represented in Fig. 397 has been recently used by the French engineering corps. In a small cylinder (11 centimetres high, and 7 centimetres in diameter) made of resinous matter not acted on by acids, four hollow zinc cylinders *z* are fixed. Inside these are four carbon cylinders c c. The metal connections which join the four elements in series are also within the resinous cylinder. It is open at *h* to allow the acid to reach the electrodes, and at *q* to allow gases and air to escape. $x\ x_1$ are the poles of the battery. When the battery is to be used, it is placed in a gutta-percha vessel z, filled with the liquid.

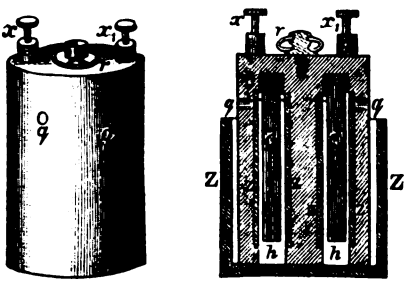


Fig. 397.—Battery for Blasting.

To avoid the transport of liquids altogether, Captain Puddot proposes to use a mixture of potassium chromate and potassium sulphate. These salts can be transported in a solid state and dissolved in water when needed.

Such a battery (containing four elements) will ignite the blasting charge at a distance of 400 metres (a quarter of a mile). The Leclanché element is also frequently used for military purposes.

Recent Improvements in Batteries.—Amongst the latest improvements in batteries may be mentioned various arrangements of the Daniell's cell to produce a constant current for experimental purposes, by Professor Oliver Lodge, and improvements in Leclanché's cell for telegraphic purposes.

A form of Leclanché's battery has been adopted which is like the ordinary trough Daniell; it consists of a teak trough, divided by porous partitions, and coated throughout with marine glue. Carbon and zinc plates are placed in alternate cells. The carbon plates are surrounded with the mixture of coke and binoxide of manganese; the zinc plates are immersed in a solution of sal-ammoniac. The plates are connected with each other in pairs by means of an iron wire, which is welded into the zinc and the lead top of the carbon plate. This form of battery thus dispenses entirely with the glass cells; the porous partitions in it are not so liable to crack as the pots in the previous form, and the short length of the connecting wire, especially if thoroughly well protected, reduces to a minimum any danger in connection with it. The maintenance now becomes a very simple matter; if the zincs are scraped clean, and the solution of sal-ammoniac renewed every three months, the battery will remain in action for years.

The latest improvement effected by Mons. Leclanché in his battery has been in the preparation of the peroxide of manganese and carbon mixture. A mixture containing 40 per cent. of peroxide of manganese, 55 per cent. of carbon taken from gas retorts, and 5 per cent. of gum lac resin, is placed in a steel mould heated to 100° C., and subjected to hydraulic pressure. The gum

lac resin is employed to consolidate the mixture. The result is that a solid homogeneous mass is produced, whose resistance is considerably less than that of the mixture first employed.

The efforts of inventors are now directed to diminish the necessity for frequent renewal of the elements of the batteries in common use, and generally to reduce the liability to disorder, and to increase the durability. The plan first adopted by Marié Davy, and more recently by Fuller, of causing the action of the battery itself to produce amalgamation of the zinc, has been adopted in several modified forms, of which those by Schanschieff are most deserving of mention.

Schanschieff's Single-Liquid Cell is a very recent invention, intended to furnish a practical element for constant use. It can be worked either open or hermetically sealed, as circumstances require. It is a simple carbon zinc element, excited by a special mercurial solution—the positive plate (zinc) being placed between two negative plates (carbon). The cell gives an E. M. F. of 1·4 to 1·7 volts, the difference being due to increase or decrease of resistance, varying with the relative positions of the positive and negative plates, and the density of the exciting liquid. Two negative elements 3″ × 4½″, and one positive 3″ × 4″ excited by 30 cubic inches of solution, give a current of 7 ampere-hours. The quantity and duration of the current are solely governed by the size of the elements and the cubic contents of the cell. The cell derives its importance from the new exciting liquid. Sulphate of mercury has been used in other batteries, in the form of "paste," but the current generated was very inconstant. Schanschieff has discovered a process by which the basic sulphate, of which it has hitherto been possible to dissolve only one part in 2,000 of water, can be readily dissolved one part in three. The chemical composition of the resulting solution produces a constant and powerful current without the aid of any depolarising substance.

The action of the cell is similar to that of the Daniell; no hydrogen is evolved, and as there is no molecular attraction between mercury and sulphuric acid when cold, there is no polarisation. The zincs are constantly amalgamated automatically by the mercury which is precipitated in the cell, and therefore there is no local action. About 95 per cent. of the mercury held in the solution is recovered, so that the working cost of the cell is very small.

No porous pots are required; no preparation of zincs, carbons, depolarising paste or liquid, and no handling of offensive chemicals is necessary; the excited liquid is limpid and odourless, and the cell gives no fumes. These advantages, combined with the great simplicity of construction, render the cell of the greatest value for many purposes.

Schanschieff's Recuperative Battery is another new invention adapted for telegraphic, telephonic, and bell work. It consists of a negative electrode (carbon) placed in a porous pot, charged with a depolarising substance, which with the positive electrode (zinc) is placed in an outer cell containing a mercurial solution. The E. M. F. of the cell is considerably higher than that of Leclanché,

and it is believed its life will be as long. The cell is recuperative, and when exhausted can easily be restored to its original energy without interfering with its work. It is made liquid-tight in unbreakable cells, so that it is portable. It can be used for giving light when it is only required for a limited period of an hour or so, such as for medical purposes, and if used to the point of polarisation, recovers itself very quickly.

Local Choice of Batteries.—Where different batteries will answer a given purpose equally well, the mere fact that the materials for one kind are nearer at hand than those of other kinds, will be sufficient to establish a preference. This reason often accounts for the local use of particular batteries for telegraphic purposes, as will be seen from the following list:

In *England*, various forms of Daniell's, Bunsen's, and Grove's batteries are used by the Telegraph Department of the Post Office, but Fuller's Mercury Bichromate Battery bids fair to be largely employed in the future.

In *France*, Leclanché's battery is largely employed, and is gradually supplanting the Marié Davy formerly used. But the Marié Davy is still preferred wherever the white crystalline bisulphate of mercury can be readily procured.

In *Germany*, the batteries mainly in use are Meidinger's (Figs. 371 and 372), and Siemens and Halske's (Fig. 369). Both of these are modifications of Daniell's battery. But as in every form of gravity battery it is essential that the solutions should remain undisturbed, this objection is causing Meidinger's to give place to Siemens and Halske's form. These elements are exceedingly cheap, and work well upon circuits offering great resistance. They are universally employed at the stations upon the Indo-European line between London and Teheran.

In *America*, Grove's battery has been employed, and is still made use of to a considerable extent on the main wires between the leading offices; but it is now being rapidly pushed aside by the modification of Daniell's known as the Callaud (Fig. 374), which is much used in France. Although this is purely a gravity battery, if frequently examined it works very well; but, in common with all its class, it requires very careful handling and treatment. Other modifications of the Daniell used in America are the Lockwood (Fig. 376) and the Baltimore, having a glass tube reaching nearly to the bottom of the jar, for the purpose of supplying copper sulphate when required. Another battery lately introduced in America is named from its inventor, the Eagles Battery. The distinguishing feature in this is that the containing vessel is formed of lead, which is made to play the part of the negative element, zinc being as usual employed for the positive. The battery is said to give very fair results.

In *India*, the Minotto is employed. This form of battery is well suited to India, where the transit of goods is slow and expensive, for the copper sulphate is an article of commerce manufactured amongst the natives, by whom it is largely employed for medicinal purposes, and it can always be procured at very short notice.

CONSTITUENTS AND CONNECTIONS OF BATTERIES.

Carbon.—It is seen from the foregoing description of the principal elements in use that carbon is used very extensively. Carbon possesses several important properties that make it useful as an electrode. Its porous character enables it to utilise a large surface without unwieldy dimensions, so as to furnish many points of contact for the hydrogen and oxygen. Again, it assists depolarisation to use a material that is capable of condensing or absorbing oxygen at its surface, is unaffected by acids, and conducts electricity. Of all the substances we know, carbon possesses these properties to the greatest extent.

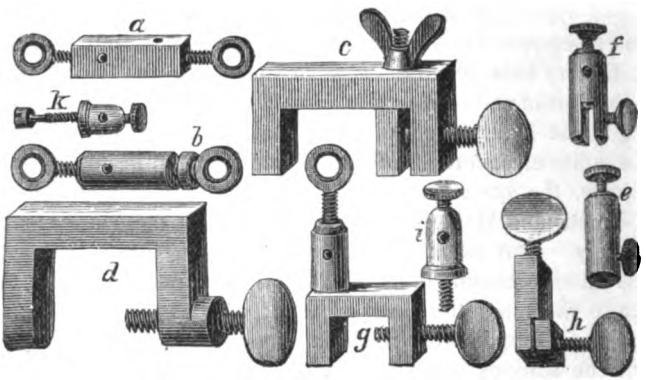


Fig. 398.—Clamps.

It is porous, absorbs gases freely, is not at all acted upon by acids, and does not offer too great a resistance to the passage of the current.

The coke which is deposited on the inside of the retorts in gas works, and sometimes is so hard as to give off sparks when struck by steel, is the best kind of carbon. As it is very difficult to obtain coke in blocks sufficiently large, it is prepared artificially. Bunsen, in 1842, produced what he called "battery carbon" by the following process: He took two parts of coke and one part of finely-divided coal, and heated the mixture till no gases came off. The mass thus obtained was, of course, too porous; it was, therefore, soaked in treacle, and then again heated without access of air, the process being repeated until the desired density had been reached. Sprague makes his carbons by mixing graphite with coal-tar to a paste, drying it and placing it in a muffler surrounded by powdered coal, and thus exposing it to a red heat. The carbon produced in this manner is also too porous, and has to be soaked either in treacle or sugar solution, and then again heated. (*See* also page 520.)

Clamps.—Clamps for fastening the carbon plates or cylinders are given in Fig. 398; these, however, are chiefly intended for natural carbon, which is less brittle. The more brittle kinds of the carbon that is artificially produced

require other arrangements, such as metal bands, metal casts, or electrotype deposits.

The Amalgamation of Zinc.—As zinc is used very extensively for electrodes, we shall give a few hints with regard to its amalgamation. Mercury, which may have been used for other purposes, is poured into a glass or earthenware vessel until it reaches about the middle of the cylinder or plate to be amalgamated. Hydrochloric acid is added, and then the zinc is immersed. The plate or cylinder is taken out and placed inverted in water. The amalgamation has to be done in a closed room, as the fumes of hydrochloric acid are very troublesome. Diluted sulphuric acid (one in ten) may be taken instead; but as sulphuric acid does not react so quickly, a mere dipping into the mercury is not sufficient, and the cylinder has to be left for a little time in a vessel containing sulphuric acid before it is immersed in the mercury. Solutions of mercury in aqua regia are sometimes used, but are not recommended.

Platinised Plates.—We often require platinised electrodes, as, for instance, in the Smee elements. The platinum coating gives a rough surface to the plate, which facilitates the removal of the hydrogen bubbles, and diminishes polarisation, oxygen being absorbed by the layers of platinum. The plate to be covered with it is immersed in a solution obtained by dissolving platinum in aqua regia. In the same solution there dips a platinum plate connected with the positive plate of a galvanic battery, the negative plate of which is connected with the plate to be coated. The platinum separates out in a finely-divided condition, giving to the plate the rough surface described.

The Acids.—Of the acids used for elements, we have simply to consider sulphuric and nitric acids, as we have already shown how to obtain chromic acid. Only dilute sulphuric acid is used; eight to twelve parts of acid in one hundred parts of water. The acid ought to be poured into the water, and the solution ought to be allowed to cool before it is used. A. d'Arsonval has given some valuable hints regarding the use of impure sulphuric acid. By adding ordinary oil, four to five cubic centimetres to a litre of acid, he caused the formation of a compound of glycerine, and separated out the impurities of the acid, such as lead, arsenic, etc., in the form of soaps. By so purifying the acid, amalgamation of the zinc is facilitated, and the dissolution of the zinc by local action during inactivity of the element is prevented. A zinc rod immersed in ordinary sulphuric acid lost 42 grammes in eight days, whilst another zinc rod immersed in a mixture of oil and sulphuric acid only lost 1·5 grammes.

Nitric acid is used concentrated, as we have pointed out already. Sulphuric acid is sometimes added to nitric acid which has been in use for some time, on account of its affinity for water. This property enables it to withdraw the water from the nitric acid, and it is clear that a better utilisation of the acid is obtained. But we ought not to leave out of consideration the fact that by adding the sulphuric acid the volume will be increased in proportion, causing dilution of the nitric acid and alteration of the resistance in the element. Schönbein recommends for iron elements nitric acid, of which one-third consists of sulphuric

acid. Wigner recommends for Grove elements two parts of nitric and five parts of sulphuric acid.

Manipulation of the Battery.—The number of elements to be used and the mode of joining up, whether in series, parallel, or mixed, depend upon the purposes for which the battery is to be employed. This has been pointed out already (page 120), but we have further to consider the placing of the battery, and the best way of making and breaking the circuit. The battery ought not to be exposed to violent changes of temperature, rain, etc.; the different vessels are best placed upon earthenware plates, or, better still, upon glass rods, so as to be easily reached.

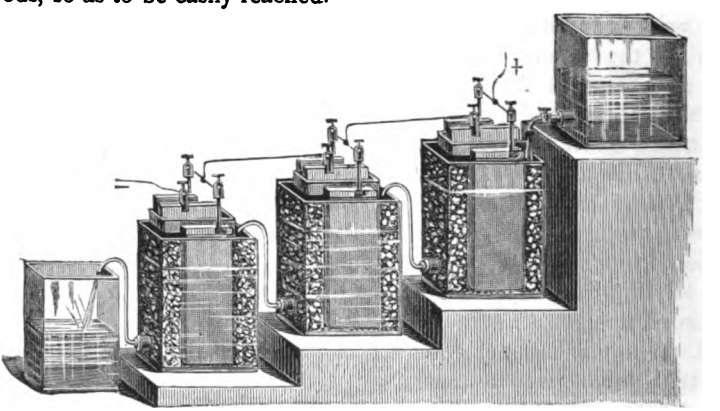


Fig. 399.—Hauck's Terrace Arrangement.

To fill large batteries, Niaudet recommends a gutta-percha tube, with a flat mouthpiece of glass at one end, and a leaden plate at the other end to sink the tube to the bottom of the vessel from which the acid is supplied. The flow can be regulated and stopped by the pressure of the fingers Siphons and small pumps are also used for emptying or filling the elements. A battery that is not to be used for a time ought to be taken to pieces after use. It is not advisable to allow the carbons to soak in water when the battery is about to be used, as the water enters the pores of the carbon and thus dilutes the acid; if, on the other hand, the battery is not to be used for a considerable length of time, carbons and porous pots ought to be washed well, as crystals are formed which tend to destroy these materials, especially the porous pots.

Batteries for electric lighting are not only required to give powerful currents, but also to be constant in their action. Powerful currents may be obtained by employing chromate of potassium elements, but the current furnished by them does not remain constant very long. To remedy this, Chuto, Camacho, Hauck, and others have devised means for replenishing the acid in proportion as it is consumed. Hauck arranges the elements as shown in Fig. 399. The acid flows drop by drop from the higher vessel; the porous cell containing the zinc

occupies the middle of the element, and the spaces between the carbon plates are filled with pieces of carbon. According to Hauck, twelve elements of this kind, the zincs of which are 15 centimetres wide and 20 centimetres high, maintain at white heat for hours a platinum wire 60 centimetres long by 1 millimetre section. The action of the battery is stopped by cutting off the supply of acid, and allowing water to flow through the elements, to prevent the formation of chrome alum crystals, which would stop up the pores of the carbon.

THERMO-PILES.

Economic Value.—In principle the generation of electricity by means of difference of temperature is preferable to its generation by means of galvanic batteries or electric machines. In galvanic elements, zinc, which is obtained from the zinc ore by using coal, is consumed. Electric machines, as a rule, are driven either by steam or gas, both of which receive their energy indirectly from coal. In thermo-electric elements, however, the stored heat of the coal is directly converted into electricity. In spite of this favourable circumstance, thermo-piles are seldom used in practice, owing to the fact that the thermo-electric elements as constructed at present are capable of furnishing only very weak currents. Antimony and bismuth were first used for the construction of thermo-piles because these stand farthest from each other in the thermo-electric series. Bunsen obtained a more powerful element by using an alloy, viz. copper pyrites. Although such an element is certainly more powerful than an antimony-bismuth element, its construction is very difficult, owing to the irregular expansion of the junctions when heated. By melting and casting the copper ore into the desired form it loses its natural structure, and the E. M. F. of the elements is considerably diminished thereby. Markus used alloys which are far distant in the thermo-electric series, and also are capable of bearing high temperatures. The thermo-pile which he constructed in 1864–65 obtained a prize from the Vienna Society for the promotion of science. The negative metal of the pile is an alloy similar to German silver. It consists of 10 parts of

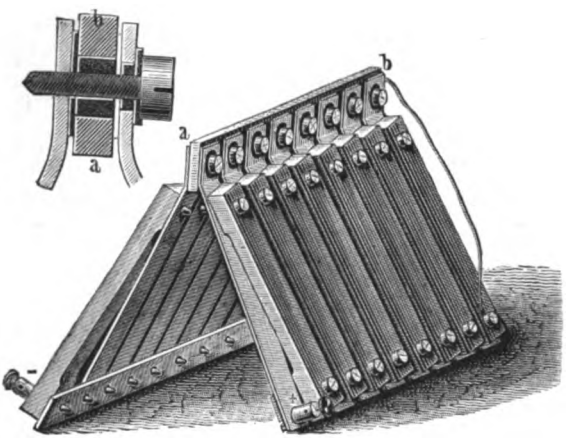


Fig. 400.—Markus's Thermo-Pile.

copper and 6 parts of zinc and nickel. The positive metal consists of 12 parts of antimony, 5 parts of zinc, and 1 part of bismuth. The negative metal is formed into blocks, the positive into three bands connected by means of screws. A number of such elements are fastened to an iron bar *a b* (Fig. 400). Mica plates are placed between the elements and bar in order to insulate them. The iron bar *a b* is heated, and the lower ends are immersed in water. A battery consisting of 130 elements is capable of furnishing 25 cubic centimetres of oxy-hydrogen gas per minute, or of maintaining a platinum wire of 0·5 millimetre in cross

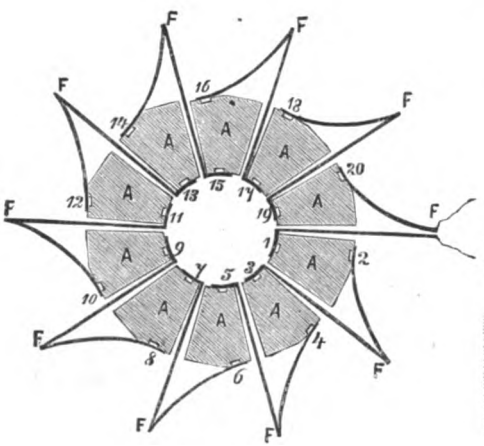


Fig. 401.—Clamond's Thermo-Pile.

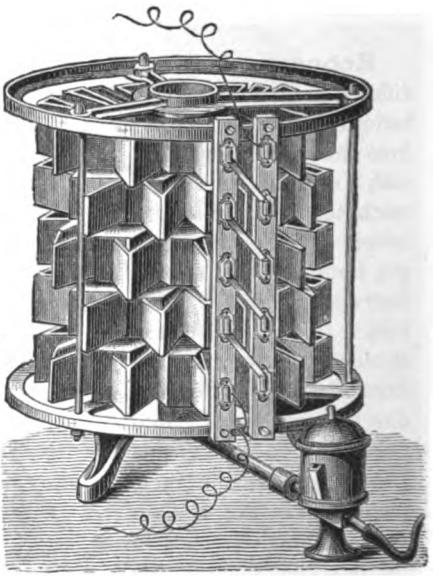


Fig. 402.—View of the Pile.

section at a red heat. The E. M. F. of an element is equal to one-twentieth of that of a Daniell's cell. The resistance in the pile very soon increases considerably, as the two alloys at the places of contact become easily oxidised.

Clamond and Mure used for their thermo-pile an alloy of zinc and antimony, with sheet iron as the second metal. Clamond's pile consists of ten elements as shown in Fig. 401. The massive pieces A consist of an alloy. The iron sheets F are fastened with one end to the inner and the other end to the outer edges of the pieces A. The sheet iron plates are made to project so as to present a large cooling surface. These annular elements are placed upon each other and insulated from each other, as shown in Fig. 402. The pole-clamps fastened to the outside of the battery allow the joining up of all the elements, either in series or in groups of ten. The inner junctions 1 to 19, filled in with

asbestos cement, form a hollow cylindrical space, in which an earthenware tube provided with a number of small holes is placed. Gas is passed through this tube, and the different little jets heat the junctions from 1 to 19 (Fig. 401), while the junctions 2 to 20 are cooled by the air. The amount of gas consumed by a battery containing five rings, each ring consisting of ten elements, according to Cazin, is 170 litres per hour; at the same time 20 grammes of copper are separated by the pile. The Paris Academy received from Th. du Moncel in May, 1879, the description of a form of the Clamond pile considerably improved, as shown in Fig. 403. The pile is built over a fireplace for coke. Before the gases and heat can escape through the chimney A, they must pass through T O P. The elements are arranged outside the cylinder P, the iron sheets of which join the vertically-arranged copper sheets D. The latter serve to produce greater cooling at the outer junctions. According to Cazin, the height of his thermo-pile was 2·5 metres and the diameter 1 metre. It consisted of two separate piles, each of which contained 30 batteries of 100 elements. Each of these piles furnished a current which was capable of producing a voltaic arc equal to 40 Carcel burners. The E. M. F. of such a pile is 109 volts, with a resistance of 15·5 ohms. Both piles together are equal to 121 newly-filled Bunsen elements, and consume 10 kilogrammes of coke per hour.

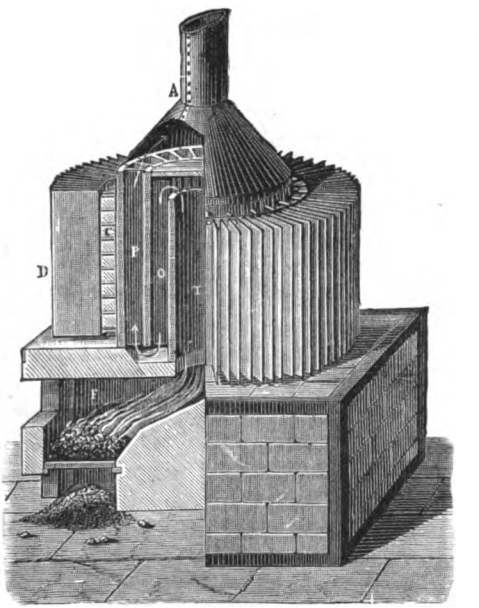


Fig. 403.—Improved Clamond's Pile.

Roe's Thermo-Element.—Fr. Roe, of Vienna, constructed his element in the following way: A copper pin (or iron coated with copper) is placed in a brass case, this again in a larger case; the larger case receives German silver wires and an alloy, which is intended to avoid the junction being screwed or soldered together. This cooling junction is formed by a brass or copper strip, to which German silver wires are soldered. An element of this kind, and the arrangement of twelve such elements to form a pile, are shown in Fig. 404. The metal strips forming the cooling surfaces are screwed to a paper ring, and form the frame of the pile. With moderate heat the outer junctions are sufficiently cooled by radiation from the vertical strips. When heated to a high temperature, the metal strips are placed with the lower ends in water. A. von Waltenhofen gave the following account of such a pile:

"Imagine a pile consisting of 128 elements divided into four groups each. Each group represents an E. M. F. equal to that of two Daniell's elements, with

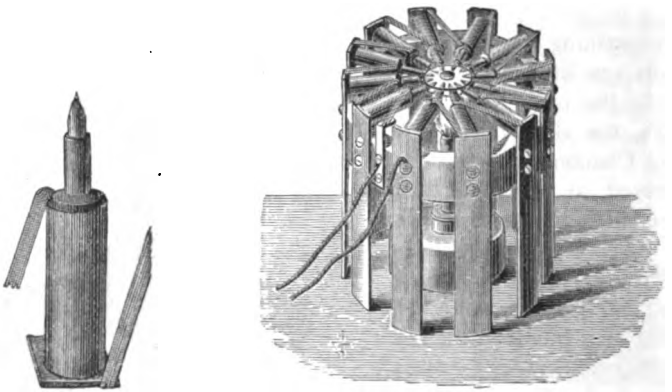


Fig. 404.—Roe's Thermo-Element.

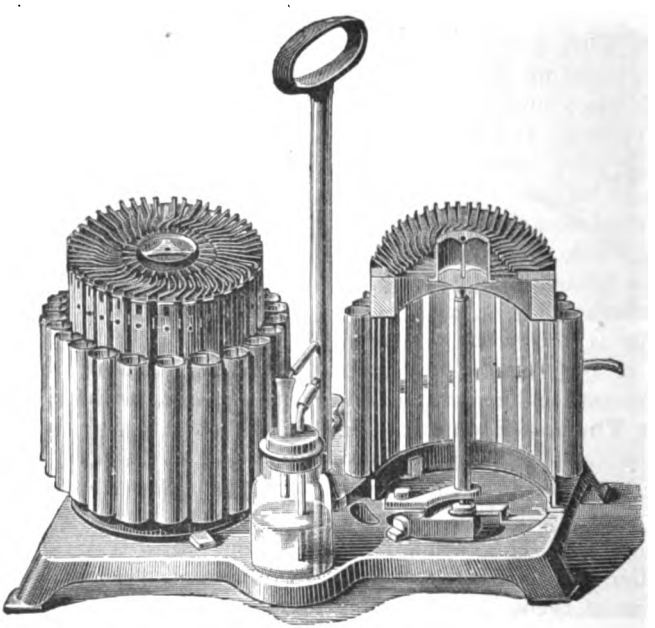


Fig. 405.—Hauck's Thermo-Pile.

a resistance of 0·8 ohm, and four groups joined in series are equal to eight Daniell's cells, with a total resistance of 3·2 Siemens' units. By joining two

groups parallel and a number of these double groups in series, an E. M. F. of four Daniell's cells, with a total resistance of 0·8, is obtained. By joining four groups parallel, the E. M. F. obtained is equal to two Daniell's cells, with limits of resistance of 0·2 ohm."

Hauck's Element.—The pile shown in Fig. 405 is constructed by W. Ph. Hauck. The E. M. F. of a single element is equal to 0·1 Daniell's cell, and the resistance 0·02 Siemens' unit. Thirty elements are capable of making a platinum wire 3 centimetres long red-hot. The piles are constructed in different sizes; two or three are placed on a frame, and are very useful for school experiments and the production of galvanic deposits.

SECONDARY BATTERIES (ACCUMULATORS).

General Principles.—By an accumulator is meant an apparatus for storing electricity. We might consider the prime conductor of an electrical machine to answer this definition, and still more so a Leyden jar or condenser. The term is now applied only to certain contrivances for storing great quantities of electricity for any length of time, and which therefore serve a purpose of very great practical importance. Leyden jars would not at all answer this end, for only small quantities of electricity can be stored in them, and even these small quantities are not entirely retained. The nature of electricity produced by friction, or by statical induction machines, neither fits it for storage nor for use. The electricity generated by the galvanic current, so much greater in quantity and lower as regards potential, answers our purpose better. In all galvanic elements combination of substances constituting the electrodes and electrolytes, no matter how varied these substances may be, will be liable to certain changes whenever the element is closed. The physical alterations which the electrodes undergo we have already considered under the head of polarisation of electrodes. Let us refer for a moment to Grove's gas battery, in illustration of this part of our subject. (*See* p. 104.) If we conduct a current by two platinum plates through water in a voltameter, we decompose the latter, and have oxygen coating the positive electrode, and hydrogen the negative electrode. If now the two electrodes of the voltameter be connected, we have another element in the circuit consisting of hydrogen and oxygen and water. A current will pass through this circuit as long as there are oxygen and hydrogen at the platinum plates. By conducting the current into the voltameter, a physical change of the electrodes has been brought about, so as to convert the voltameter itself into a galvanic element. This second element then owes its existence to the first. Therefore, the first element, or rather elements (for several elements are required for the decomposition of water), are called "primary." The second element, or elements, are called "secondary." The primary battery gives out a current of electricity, and the secondary acquires a condition which gives it also in turn the power of producing an electric current.

The process seems really to represent a storage of electricity. The electricity

conducted into the voltameter from the primary element, *can be got out again from the voltameter.*. The storage there is not the same as in the Leyden jar or condenser, but is a conversion of electrical energy into chemical energy, which may be reconverted into electrical energy. The primary current separated hydrogen and oxygen from each other, and stored them in the electrodes ; in the secondary element oxygen and hydrogen unite again, the energy of chemical separation disappears, and electricity again appears. Properly speaking, then, the secondary element is not an apparatus for storing electricity, as electricity simply, but an apparatus by means of which electricity is reconverted into chemical energy, which by proper arrangements can be turned back into electricity. On this ground, therefore, many consider that the term accumulator is not altogether an appropriate one for these secondary elements.

We have now to consider which would be the best way to utilise the process for practical purposes. The simple voltameter, *i.e.* two platinum plates in acidulated water, would not be easily available for practical purposes. Such a secondary element would last only for a very short time ; in other words, the voltameter is not capable of storing large quantities of electrical energy in form of the chemical energy due to separation. The electrodes, however, may not only undergo physical changes, they may also be chemically changed by oxidation or reduction. When this is the case, and the electrodes are connected, we have a secondary element that will furnish us with electricity as long as the oxygen of the oxidised electrode lasts. It is on this principle that the secondary elements in use at present have been constructed.

History of Secondary Elements.—Before we consider the secondary elements themselves, it will be useful to sketch briefly their history. Gautherot in 1802 observed that during electrolysis the platinum wires which served as electrodes became polarised, and that by the absorption of oxygen and hydrogen they became electrically different. By connecting the two electrodes, he obtained a secondary current.

A short time after (1803) J. W. Ritter constructed the first secondary battery. Discs of the same metal, having moistened pasteboards between them, were arranged in the same manner as Volta's pile, and their poles were connected to the poles of a Volta's pile. When the current of Volta's pile was allowed to pass through the secondary battery for some time, the battery assumed the properties of a pile. The metal plate of the secondary battery, which was connected with the positive pole of Volta's pile, became a positive pole, and the plate connected with the negative pole became a negative pole. Hence through the closed circuit of the secondary battery, a current flowed in the opposite direction to that of the primary current. Although Ritter was well aware of the importance of his experiments, he did not follow them up at the time, for the simple reason that he had not the means.

It was not until after G. Planté's extensive investigations that the construction of secondary batteries was completely achieved. In the *Comptes*

Rendus of the French Academy* appears one of the earlier formal accounts of Planté's labours, and from that time to this various notices of his work are to be found in the scientific publications. In 1879 he published a book entitled *Recherches sur l'Électricité*,† which contains a full account of all that he has done. In an article written by Kareis (*Zeitschrift des Wiener electrotechnischen Vereines*) he says: "When we remember that the electricians of the present day have endeavoured to make practical use of the energy stored up in the accumulators, it becomes difficult to believe that the originator did not entertain similar intentions. We are so accustomed to make practical use of every new discovery for our immediate and personal benefit, that we cannot help having a very high regard for men who are willing to leave the practical utilisation of their inventions to others. Such a man is Gaston Planté. Whoever enters his

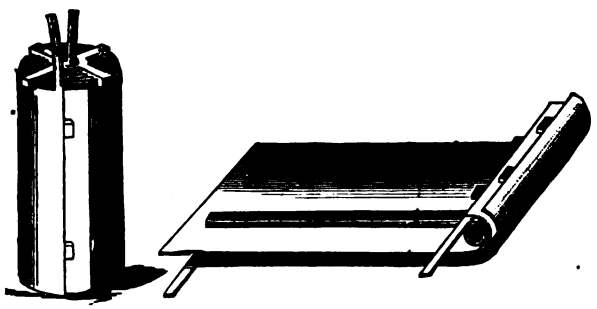


Fig. 406.—The Planté Lead Plates.

laboratory in the Rue des Tournelles, finds that here science is neither the milch-cow nor the maid-of-all-work; she is a companion that goes hand in hand with her master, reverenced by him on the one hand, and aiding him in all his endeavours on the other."

Planté's Element.—The principle which Planté followed in the construction of his secondary element, is simply the chemical conversion of the electrodes by means of a current. Numerous experiments proved that the best metal for this purpose was lead. Two lead plates (Fig. 406), each $1\frac{1}{2}$ millimetres thick, furnished with a conducting strip, and insulated by means of india-rubber bands (0·5 centimetre), are laid upon each other and then rolled up into a cylinder, which is held in position by means of an ebonite cross. The cylinder is placed in a glass or gutta-percha vessel containing diluted sulphuric acid (one part in ten). The lid of the vessel has several openings for the passage of the conducting wire and to allow the escape of gases. Two vertical metal bars are frequently attached to the lid, A A (Fig. 407), and are connected by a platinum wire F, which can be made red-hot by discharging the secondary element. The bands G and H are in connection with the metal bands M′ and M. M′ is con-

* Vol. i., p. 640. † Paris: A. Fourneau.

nected with A on the left, and M is connected with A through the spring R on the right. When B is screwed down, H is also connected with A. To charge the secondary element two Bunsen elements are sufficient. The Bunsen elements are joined parallel with the secondary element, when B is screwed down, and the current of all the elements will pass through the wire F. When the secondary element is charged the following changes occur: The electric current decomposes the water, and the oxygen separates out at the positive leaden plate, and the hydrogen at the negative leaden plate. The positive leaden plate becomes oxidised and receives a brown coating of lead dioxide, whilst the negative leaden plate remains bright and receives only pure metallic lead. If now the two plates be connected by means of a wire, a current will circulate through the system, due to the production of an element consisting of lead dioxide, lead, and diluted sulphuric acid. The current in this element will have the opposite direction to the primary current, and will cause the lead oxide to be reconverted into metallic lead. When the reconversion is at an end the current ceases, and the secondary element is then said to be discharged. The reaction of the sulphuric acid in the secondary element is of great importance. The sulphuric acid combines with the lead to form lead sulphate, a compound which is very insoluble, and which covers the leaden plates with a white layer, thus preventing the lead from further corrosion. The current decomposes the lead sulphate, forming lead dioxide at the positive leaden plate, and lead in a spongy form at the negative leaden plate. The production of the spongy form of lead increases the surface, and consequently the effect of the plates. By repeating the process of charging and discharging the secondary element, the spongy mass will be increased through the action of the sulphuric acid, and, further, when the secondary element is charged the upper layer of the lead dioxide will be reconverted into lead sulphate, which will prevent the further decomposition of the lead dioxide, and thus allow the element to keep its charge for a greater length of time.

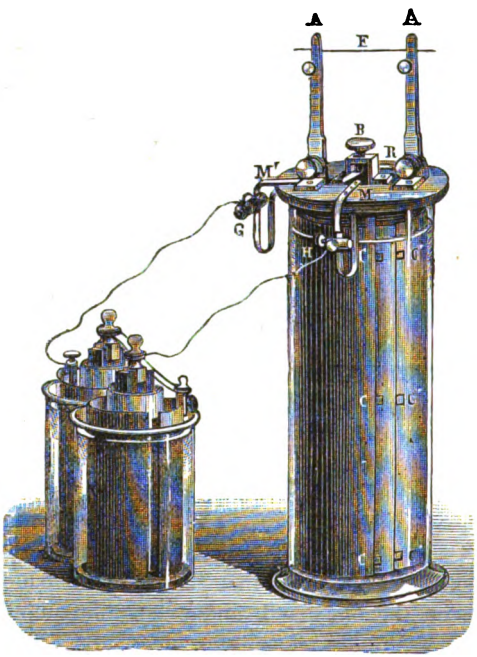


Fig. 407.—The Planté Element.

In order to completely charge a newly-constructed Planté's element, it

is not sufficient to allow the primary current to pass through it for a considerable length of time; for as soon as the first layer of lead dioxide is formed, the lead beneath it will be protected from the action of the oxygen. A short time after passing the primary current a brisk evolution of gas takes place, and if the secondary element be closed the oxidised lead will be again reduced, and the second electrode will become oxidised, thus causing both electrodes to have spongy surfaces. The primary current will produce a greater amount of lead dioxide when allowed to pass through the secondary element again. We observe that the brown colour of the oxidised lead becomes lighter, until it appears almost white, when a charged secondary element is left for some time in the enclosed circuit. The cause of this alteration is due to the action of the sulphuric acid. It turns some of the lead dioxide into lead sulphate, which has a white colour, and which by mixing with the brown dioxide causes it to assume a lighter colour. At the next reduction the lead sulphate is also converted into lead, which adheres in grains on the surface of the plates. This will explain why a secondary element does not attain its full energy after its first charge. Hence, in order to prepare the battery for use, and to bring it more rapidly into the condition it would otherwise arrive at after prolonged use, it is first repeatedly charged alternately in opposite directions, then charged and allowed to stand for some time; then discharged and charged again. According to Planté, a secondary element should be charged thus: The primary current is allowed to pass through it for about a quarter of an hour; it is then discharged. The current now passes through in the opposite direction a little longer; it is again discharged, and so on. When the time has been increased to two hours, it is left during the night, and discharged the next day. It is then charged once more, and left for about eight days. After this somewhat lengthened process has been gone through once, the apparatus need only be charged once when wanted. After discharging a secondary element, we find that if we leave it for some time it will again give a current. This phenomenon will be most observable when the first discharge is very powerful. This is due to the fact that during the discharge the current passing through the liquid will decompose it into its constituents, separating the hydrogen at the lead dioxide plates, and oxygen at the leaden plate; the oxidised lead will become reduced by the hydrogen, and the lead will become oxidised by the oxygen, *i.e.* the two plates become polarised. The polarisation current thus caused becomes weaker and weaker until it ceases altogether, its direction being opposite to the direction of the primary current.

Methods of Joining.—Secondary elements can be joined up both in series and in parallel order. Fig. 408 represents such a battery, consisting of twenty elements. The commutator consists of the wooden beam c c, flanked with copper bands which are pressed by the springs *r r*. The front springs are connected with all the poles of one kind, and the back springs with all the opposite poles. In this position of the commutator the elements are joined parallel, thus representing one element having plates of large dimensions. Each

of the copper bands is connected with a clamp G, through which a platinum wire runs, and which can be made to glow for a short time. When the commutator is turned through 90° by means of the knob B, the metal pins fastened to the beam C C will come under springs *r r*. The opposite metal pins are then connected with each other, and when the commutator assumes this position the elements are joined in series. The wires from the poles of the battery are connected with the clamps T T, between which a platinum wire runs, and which when of sufficiently small cross section will be maintained at white heat.

By means of secondary batteries a high potential is obtained. With two Bunsen elements and a secondary battery, the same effect may be secured as

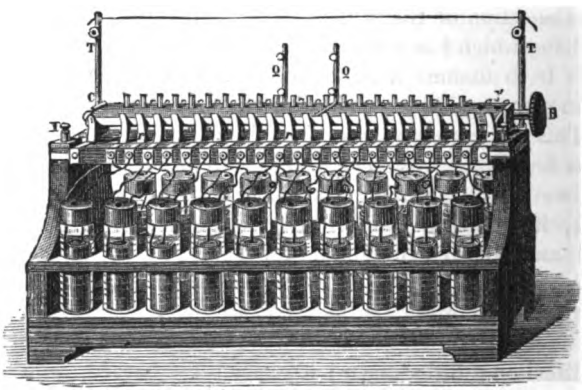


Fig. 408.—The Planté Battery.

with a large battery consisting of many Bunsen elements. Numerous experiments require a current of high potential, which can only be obtained by a battery of many elements.

A battery of secondary elements, when once arranged, gives no further trouble, except to see that the secondary elements are always joined in parallel order whilst being charged.

Strength of Secondary Batteries.—Two Bunsen elements are sufficient to charge twenty secondary elements, having the same effect as thirty Bunsen elements; but a secondary battery consisting of twenty elements which have had a current from two Bunsen elements passing through them for one hour, cannot therefore give a current for one hour equal to that of thirty Bunsen elements. To obtain this result the two elements would be required to supply a current for fifteen hours, and indeed for a longer time than this, as the conversion of energy is always attended by loss. According to the experiments made by Planté, only nine-tenths of the energy is returned. The amount of charge which a secondary element possesses corresponds to the quantity of matter separated by electrolysis, which again is proportional to the work that

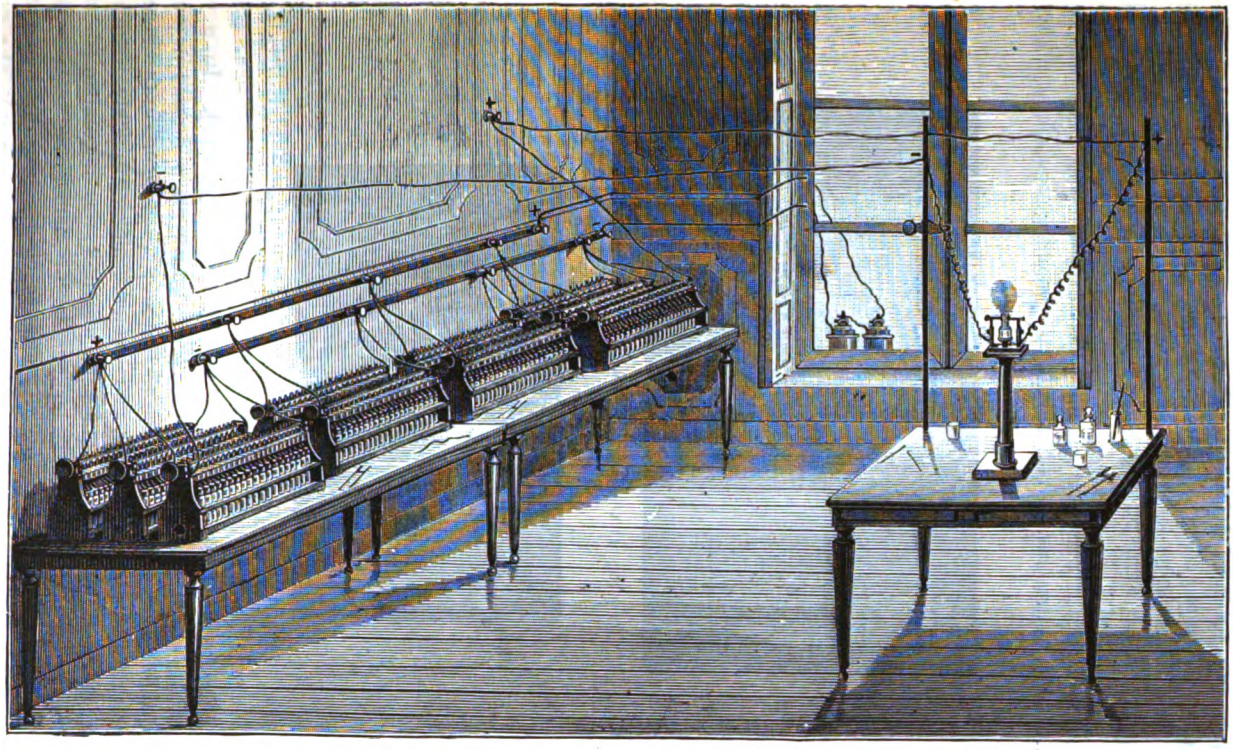


Fig. 409.—Large Planté Battery.

the current is capable of doing—in other words, proportional to the quantity of zinc dissolved in the element. The amount of work to be got from a secondary battery must therefore be less than the amount of work put into it, as the conversion of one form of energy into another cannot be brought about without loss.

Planté constructed batteries containing as many as 800 elements, for his experimental investigations. With a battery containing 200 elements he pro-

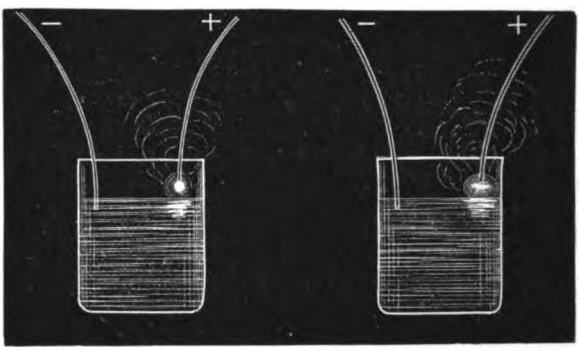


Fig. 410.—Experiment with Planté Battery.

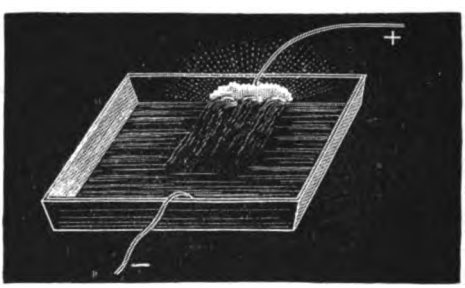


Fig. 411.—Experiment with Larger Battery.

duced a phenomenon similar to that of ball lightning (Fig. 410). In a vessel containing salt water, or acidulated water, the negative electrode was immersed, and the positive was made to approach the liquid; when a certain distance was reached a luminous ball of vapour was formed, spinning quickly round, and becoming gradually flattened. This phenomenon was accompanied with a considerable noise. By using a larger number of elements, Planté obtained a sheaf of glowing balls by allowing the negative electrode to dip into a vessel containing salt water, and bringing the positive electrode near it. The phenomenon produced (Fig. 411) was compared to the formation of breakers by a spring tide.

Special Applications of Planté Batteries.—Fig. 412 represents the apparatus known as the "briquet de Saturne," which is used for lighting candles and lamps. It consists of a little mahogany box on the front of which a little candle is fixed, and above it a fine platinum wire is stretched. Inside the box there is a secondary element, the current of which passes the platinum wire, causing it to glow whenever contact is made by means of the spring T. The clamps C are used to receive the wires from the primary or charging battery.

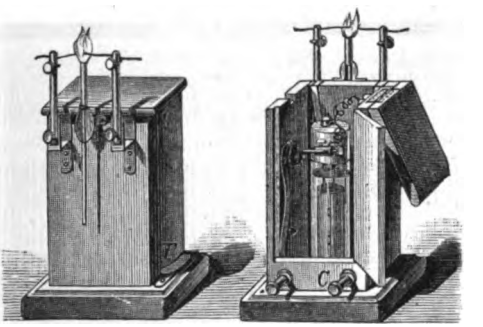


Fig. 412.—Briquet de Saturne.

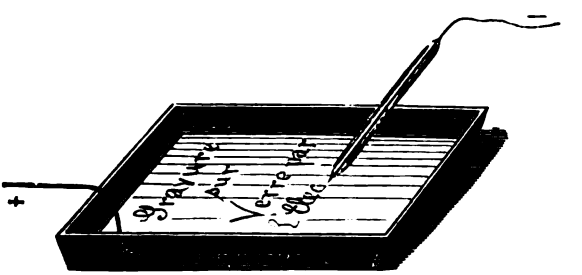


Fig. 413.—Engraving on Glass.

Glass Etching by Electricity.—Glass can be etched by means of electricity (Fig. 413). The plate to be etched is put into a flat vessel which is connected with the positive pole of the secondary battery. The plate is covered with a concentrated solution of saltpetre, and is then written upon with the negative electrode, which is insulated by means of a glass handle.

Planté's Rheostat.—By means of the accumulators, electricity of low potential can be converted into electricity of high potential; but still higher potential may be obtained by means of the rheostat constructed by Planté (Fig. 414). The several plates consist of mica or gutta-percha, having tinfoil on both sides. About eighty of these plates are placed in a frame and carefully insulated from each other. The commutator is one of the ebonite cylinder form. During the charging the commutator is so arranged that all the plates

are joined in parallel order, and connected with the poles of a secondary battery: during discharge the plates are placed in series. Planté connected the poles of this apparatus with a secondary battery consisting of 800 elements, which

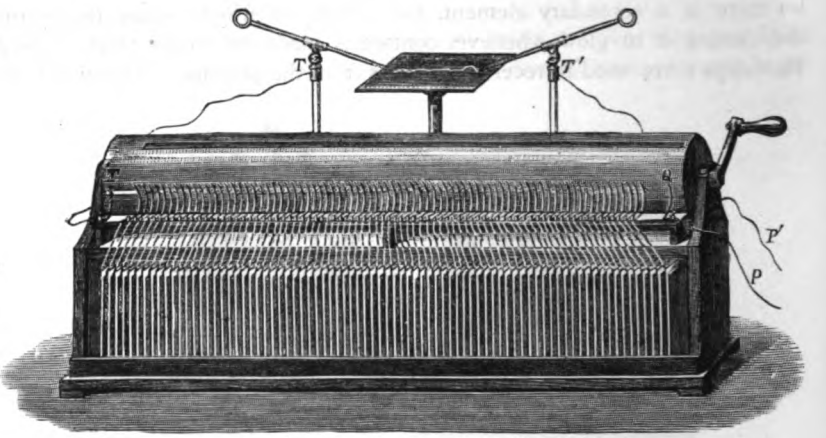


Fig. 414.—The Rheostatic Machine.

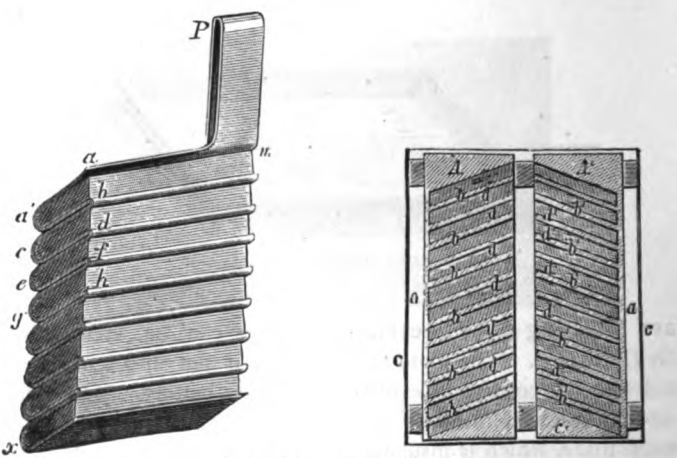


Fig. 415.—De Méritens' Secondary Element.

had been charged for several days with two Bunsen elements, and he obtained a series of sparks exactly like those from a condenser connected with an electrical machine.

Stimulated by Planté's experiments, many electricians have taken up this subject, and endeavoured to improve secondary elements in different ways: (1) by

enlarging the surface of the two leaden plates; (2) by properly preparing the leaden plates so as to shorten the process of charging for the first time; (3) by using other metals instead of lead in order to diminish the weight of the elements.

De Méritens' and Similar Secondary Elements.—To give as much surface as possible to the leaden plates, De Méritens uses leaden plates two millimetres thick, which he folds, as shown in Fig. 415, so that at one fold the surfaces of the lead bend into contact, while at the alternate folds *a c e g* they leave spaces *b d f h*, which are filled with lead shot. The strip P connects the whole plate. Two such plates are placed in a vessel of gutta-percha

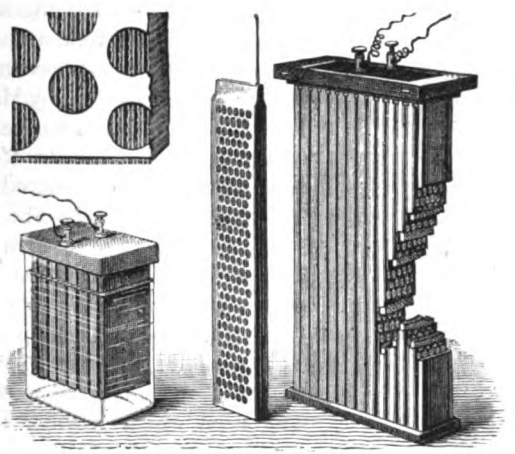


Fig. 416.—Kabath's Secondary Element.

filled with diluted sulphuric acid, the plates being so placed that their open ends come uppermost. Sellon and Volckmar make use of perforated lead plates, the openings of which are filled with spongy lead. Changy places a porous cell in a leaden vessel, and fills the intervening spaces with sheet lead. Kabath's element consists of straight and waved lead strips, 0·1 millimetre thick, arranged alternately and held together by perforated plates (Fig. 416). In this manner plates eight or nine centimetres wide are formed, offering a fairly large surface to the fluid. Each plate consists of 80 to 100 leaden bands, and is connected with a conducting wire. Kabath arranges twelve of these plates vertically to form an accumulator. The plates are joined alternately with the one pole and with the other. In front of both the first and the last plate a massive leaden plate is placed. The containing vessel is made of wood coated with lead.

Faure's Secondary Battery.—Of those elements in which the process of charging is shortened, we have to name in the first place that con-

structed by Faure, which has attracted much attention and has met with considerable success. It consists of two leaden strips, one of them 600 millimetres long by 1 millimetre thick, and the other 400 millimetres long by 0·5 millimetre thick. It is manifest that the "storage capacity" of such a battery will depend largely upon the thickness of the layers of dioxide and of spongy metallic lead, which are formed on its plates, for the thicker these layers the more chemical action will they develop in being reduced to sulphate, and the more chemical action will they absorb in being changed back again into oxide and metal respectively. Hence the repeated reversed charging employed by Planté in preparing his cells.

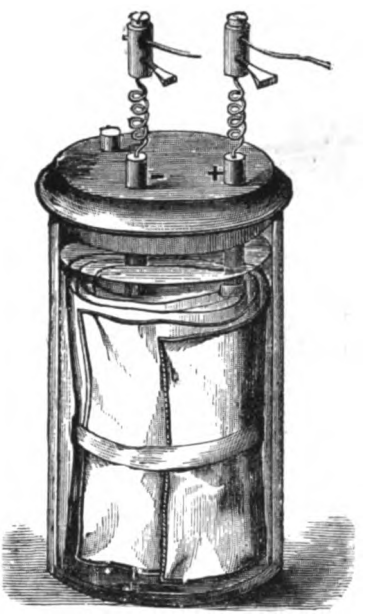


Fig. 417.—The Faure Element.

A very simple and ingenious method of saving the loss of time and energy involved in this preparation is the characteristic feature of the element devised by M. Camille Faure. He coats both plates before rolling them up with a paste of red oxide of lead (minium), made into a paste by diluted sulphuric acid. The large plate receives 800, the small plate 400 grammes. The minium is then covered with parchment, and the whole covered over with felt. It is placed in a cylindrical leaden vessel, having its inside coated with minium and felt. Such an element weighs 8,500 grammes without the liquid. The form which Reynier has given to the Faure element is shown in Fig. 417. The leaden vessel is replaced by a glass cylinder, and the felt by a texture which is not destroyed so quickly. As soon as the plates coated with minium are immersed in the diluted sulphuric acid, the minium is converted into lead dioxide and lead sulphate. The current has now only to complete the formation of lead dioxide on the one plate, and to reduce the compounds of lead on the other. According to Uppenborn, a Faure's element has an E. M. F. of two volts and weighs 25 kilogrammes. With three Siemens' machines (model D2) 150 elements can be charged in ten hours; if left unused they lose 1·5 to 2 per cent. per day.

On the first action of the charging current, the sulphate of lead on one plate is reduced to a sponge of metallic lead, while that on the other is oxidised into peroxide. This is the only difference between the "secondary battery" of Planté and the "storage battery" of Faure. Both operate on the same principle and in the same way, with probably some considerable improvement in efficiency, *i.e.* capacity, in the Faure arrangement. Both batteries are frequently

made in the form of numerous flat plates covered with some woven fabric, and packed near together in a rectangular box filled with dilute acid. The sole novelty in the Faure device is in the use of the porous coating of decomposable substance, by which a thick layer of active material can readily be obtained on both plates of the battery. The Faure cells as they are now constructed for industrial use are rectangular in shape, and are arranged in rectangular boxes of wood impregnated and heavily coated with an asphalte varnish, which enables them to withstand the action of the acid solution which fills them. The weight of a single cell of such a battery is about ninety to one hundred pounds.

The great interest which they have excited at the present time arises largely from two causes: first, the enormous improvement in dynamo-electric machines, by reason of which electric currents can be supplied at a small fraction of what they used to cost when they were obtained only from galvanic batteries; and secondly, the great need developed in the attempts to apply the cheap electricity furnished by dynamo machines to various uses, for some means of storing the electric force either actually or practically.

In order that this desired result should be obtained in a way commercially valuable, several conditions must be fulfilled: (1) The storage must not involve any great loss of energy in the charging; (2) the stored energy should be retained with little loss: (3) the cost of the storage apparatus should be moderate; (4) the apparatus should be within moderate limits of bulk and weight; and (5) it should be enduring, and not wear out so as to require frequent replacement.

The most interesting tests of the Faure battery, with a view of determining in how far it fulfilled these conditions, were made at the Conservatoire des Arts et Métiers in Paris, by a committee of which M. Tresca was president, and MM. Allard, Le Blanc, Jubert, and Pottier were members. An extensive extract from the report of this committee to the French Academy will be found in the *Telegraph Journal and Electrical Review*, of London, for March 18, 1882, vol. x., p. 196.

Passing by all details of the experiments, we will only note the general facts and results. The battery experimented upon consisted of 35 cells weighing about 95 pounds each, or in all 3,325 pounds, say 1½ tons. It was charged by a Siemens dynamo-electric machine, which absorbed the mechanical energy of 1·558 horse-power during 22 hours 45 minutes, which would be equal to one horse-power for 35 hours 26 minutes, or in foot-pounds 70,158,000. Of this mechanical energy 34 per cent. was expended in useless work in the machine and battery during the operation of charging, and 66 per cent. was stored as chemical energy in the battery. Of this stored energy, 60 per cent. was recovered as electric energy. This would amount to about 27,782,700 foot-pounds, or one horse-power for 14 hours 4 minutes. In other words, the actual work of one horse for 35½ hours, after being stored in 1½ tons of battery, could be recovered to the extent of about 14 hours' work of one horse, or the equivalent of the same in electric or other energy. Thus, Mr. Edison's 16-candle electric lamps require about one-sixth of a horse-power each, and therefore six of them could

be run for 14 hours with the energy stored in this battery as above stated. Mr. Edison's smaller lamps, which give about eight candles each, or the same light as an ordinary German student's lamp, require but half as much power, and thus six of them could be run for 28 hours by this same battery.

This is, of course, not a high degree of efficiency; but, as the above-named committee remark in their report, "In many cases the loss would be fully counterbalanced by the advantage of having at hand and entirely at one's disposal so abundant a source of electricity."

The occasion of the losses experienced in the storage battery, and also the exact character of the actions, chemical and electrical, which go on in it, are very fully developed in a paper on "The Chemistry of the Planté and Faure Accumulators," by J. H. Gladstone and Alfred Tribe, in *Nature*, of January 25 and March 16, 1882. The main sources of loss there shown are, first, local action between the negative lead plate and the peroxide of lead deposited upon it; and second, the resistance of the oxide and sulphate to the passage of the current, by reason of which energy is lost by being converted into useless heat in the battery both at charging and discharging.

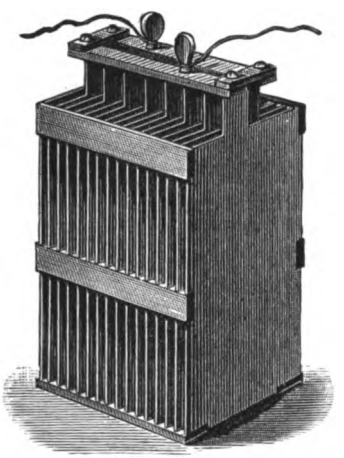


Fig. 418.—Schulze's Secondary Element.

By so regulating the discharge of the battery as to reduce this loss, and by giving seasons of repose in which the battery recovers some of its deterioration, Messrs. Ayrton and Perry succeeded in recovering 82 per cent. of the power put into one of these batteries. A single cell, weighing 81 pounds without the dilute acid, yielded, in three discharges of six hours on three successive days, an electric current whose total energy was 1,440,000 foot-pounds, which represents about one horse-power exerted for about three-quarters of an hour. This is almost double the efficiency per weight of battery shown by the French experiments, and the recovery of 82 in place of 60 per cent. of the stored energy would indicate a much greater efficiency in this respect also.

Experiments in using the Faure battery for industrial purposes have already been made in various directions. It has been employed to run street cars and other vehicles (including even velocipedes), to propel boats, to work sewing machines and others requiring a small amount of power, to illuminate houses and single rooms, and also steamers and railway carriages. As yet it has only been shown to be economically valuable where peculiar conditions protect it from competition with other means of effecting the same results more directly. Thus it has been used in France at the establishment of M. Duchesne-Fournet, where linen cloth is bleached by exposure to sunlight on

bleaching-greens, to run a train carrying out the cloth from the factory to the green, and to wind in the cloth from the green after it has been bleached. An ordinary steam engine could not be used in this case on account of its smoke and cinders. Again, in railway cars it may be more convenient to use a Faure battery than to have a dynamo-electric machine, either run by a special engine or by the motion of the train. The latter would of course be impracticable without some storage arrangement to provide a light when the train stopped.

Indeed, as a regulator of electric currents, to equalise them, or bridge over brief interruptions of the generating machines, a storage battery would seem to have a wide application.

As is well known, a number of these Faure batteries were recently used to maintain four incandescent lights when required on the steamer *Labrador*, during her passage to New York.

Modifications of the Faure Element.—To give the lead plates a loose surface, G. Schulze, of Strasburg, covers them with powdered sulphur, and then heats them. If now the plates be immersed in dilute sulphuric acid, and the current allowed to pass, at one plate the sulphur will combine with the hydrogen and escape as sulphuretted hydrogen, leaving spongy lead behind, whilst at the other plate lead sulphate and lead dioxide will be formed. The elements consist of plates 23 centimetres high, 12 centimetres wide, and 0·5 millimetre thick, which are suspended and connected as shown in Fig. 418. The lead of an accumulator consisting of thirty plates weighs 8 kilogrammes. The total weight, including the fluid, is 10·5 kilogrammes. When charged, the element possesses a resistance of 0·005 ohm, which is increased during the discharge to 0·015 ohm by an E. M. F. of 2·15 volts. De Calo uses for his secondary elements plates consisting of spongy lead coated with minium and placed in little sacks. Kornblüh uses lead wire gauze coated with minium; ten plates of 6 millimetres thickness are joined to form one element. The secondary element constructed by Böttcher is shown in Figs. 419 and 420. The negative electrode here consists of sheet zinc z bent into a U-shape. Within it is suspended the waved leaden plate P, coated with litharge; and, to prevent contact, parchment F is wrapped round it. The several plates are fastened to a frame which can be moved up and down. Each element receives 300 grammes of zinc sulphate, and separates zinc out during the charge, forming lead dioxide at the lead plate. The charged element then consists of lead dioxide, zinc, and sulphuric acid. If the plates were not taken out of the liquid, the zinc would again dissolve in the sulphuric acid; to prevent this the plates are arranged as shown in the figure. During the discharge zinc sulphate is formed in the element, and at the same time the lead dioxide is reduced. According to Böttcher, the element furnishes a current after discharge, on account of the galvanic element, consisting of lead, zinc, and zinc sulphate; this current cannot, however, be of very long duration, as polarisation will quickly set in. For practical purposes the form would have to be altered.

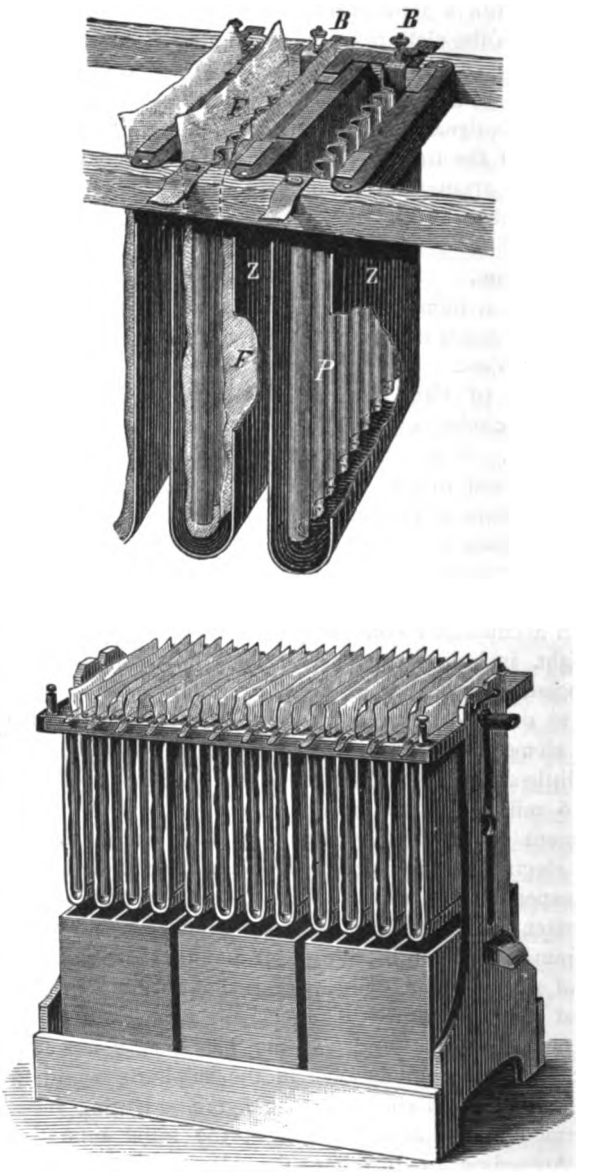


Fig. 419.—The Böttcher Element.

THE CHARGING OF SECONDARY ELEMENTS.

Galvanic elements, thermo-piles, or magneto-electric machines may be used for this purpose. The latter are especially to be preferred when available, for practical reasons. For smaller batteries, such as are required in laboratories, galvanic elements are generally used. To use elements such as Leclanché's would not be advantageous, as with a small resistance in the outer circuit, such as the secondary element would offer, the current of these cells would soon diminish. Bunsen's elements, however, would answer well. As the primary current causes a current in the secondary elements, which has the opposite direction to it, it is necessary that the source of electricity furnishing the primary current should possess a higher E. M. F. than the secondary element. For instance, in order to charge twenty elements of a secondary battery (E. M. F. = 2 volts each) joined in series, a source of electricity must be employed, the E. M. F. of which is more than 40 (2 × 20 volts). If, however, we had only one, the E. M. F. of which is, say, 3 volts, the secondary elements would then have to be joined parallel, so as to represent one element with a large plate. If we can choose our E. M. F. it is well to use currents of moderate strength, and to arrange the secondary elements of large batteries in groups, placing the elements in the several groups in series, and the groups themselves parallel. The number of elements which each group ought to contain depends, of course, upon the E. M. F. of the primary current.

Modes of Charging Secondary Batteries by means of Magneto- and Dynamo-Electric Machines.—As we have said, magneto-electric machines are preferable for the charging of secondary elements for certain reasons. By using magneto-electric machines the process is very simple, as the electro-magnets in these generators are independent of the machine current, and cannot change their poles as a dynamo machine might do. With a high E. M. F. and a small quantity of machine current, it is best to arrange the secondary elements in series. But with a large quantity and small E. M. F.—as, for instance, when the electricity is produced by such generators as are used for the separation of metals in electrotyping—it is best to arrange the elements into groups, and to form these in parallel order. Better results are obtained where the process is not hurried. When dynamos are used, certain precautions must be taken. The elements may be joined to the machine in two different ways, as shown in Figs. 420 and 421. In the first case the armature A, electro-magnets E, and the secondary battery are all in the same circuit, the secondary elements s forming the outer circuit of the machine. We know that the machine is extremely sensitive to variations in the outer circuit, and every such variation influences the current produced by it. The secondary elements will send a current through the circuit in the opposite direction to the primary current. The direction of current, then, in the total circuit, will depend upon whether the E. M. F. of the machine current, or the E. M. F. of the secondary elements, prevails. The secondary battery current might prevail when the machine

chosen is not sufficiently powerful for charging the secondary elements, or if the machine has not the proper speed; or when unforeseen circumstances happen, such as the breaking of a belt, etc. The current of the secondary elements will then flow into the machine and change the polarity of the magnets, which, if not corrected, might injure the machine. When, however, the elements are joined parallel, as shown in Fig. 421, re-polarisation of the magnets

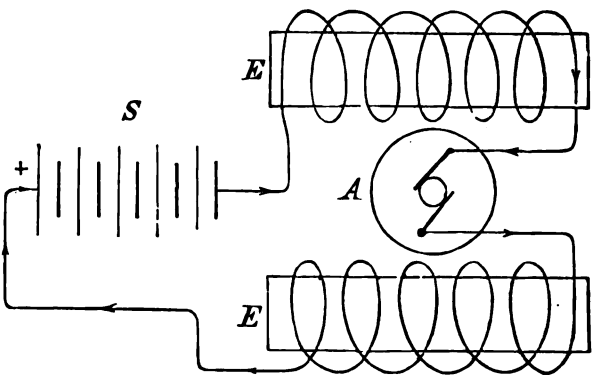


Fig. 420.—The Charging of Secondary Batteries.

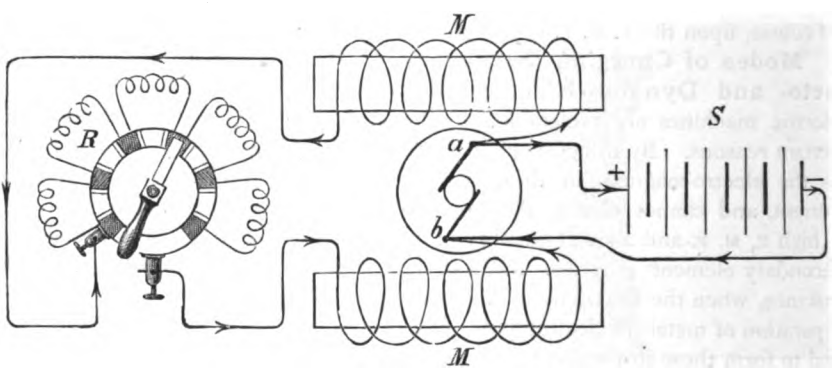


Fig. 421.—The Elements joined Parallel.

is avoided. Two circuits are connected with the brushes of the commutator; one circuit has the elements S, the other the coils of the magnets and an adjustable resistance or rheostat R. As the current divides so that the currents in the different branches are inversely proportional to their resistances, by inserting the necessary resistances the current can be regulated as required for charging the secondary elements. If with this arrangement it should happen that the current in the secondary elements becomes stronger than that of the machine, although it will flow into the coils of the machine, as in the first case, it will not change the polarity of the magnets. Positive electricity here flows

from the battery towards *a*, and then into the armature, and the coils of the electro-magnet. (*See* Fig. 421.) Although re-polarisation is avoided, the process of charging even here requires constant attention.

In order to admit of the employment of irregular sources for the charging of secondary elements, an apparatus such as that represented in Fig. 422 is used. By means of this the connection between the battery and the source of electricity is broken whenever the current of the machine diminishes beyond a certain limit. The instrument, however, will not only effect this purpose, but will also connect the elements with the machine again, as soon as the strength of the current has sufficiently increased. The instrument represented in Fig. 422 was devised by Hospitalier; it consists of the magnets s s′ and the electro-magnet T T′, the coils of which are made of wires of different thicknesses. The armature N N′ is fastened at O, and its length of oscillation may be regulated by means of the screws V V′. The point E presses against either the springs A B or the springs C D, according as the armature N N′ is attracted by the electro-magnet T T′ or the steel magnet S S. The poles of the secondary elements are joined at P P′, and the poles of the machine at M M′. As long as no current enters at M′ the armature N N′ is attracted by the steel magnets S S′. In this position the springs C and D will be pressed together at 2 and E. If the current be only feeble, it will have to flow through the thin wire of the electro-magnet from M over T T′ to H, then through C D I E and M′, back to the machine. Passage through the thick wire is broken at I, between the springs A B. If, however, the current has the required strength, the electro-magnet will become so powerful by having this current flowing through the thin wire, as to attract the armature N N′. It thus causes the spring C D to lose contact, as shown in the figure. The direction of the current will now be as follows: From M through the thick coils of the electro-magnet to G, through the springs B and A to F, then into the

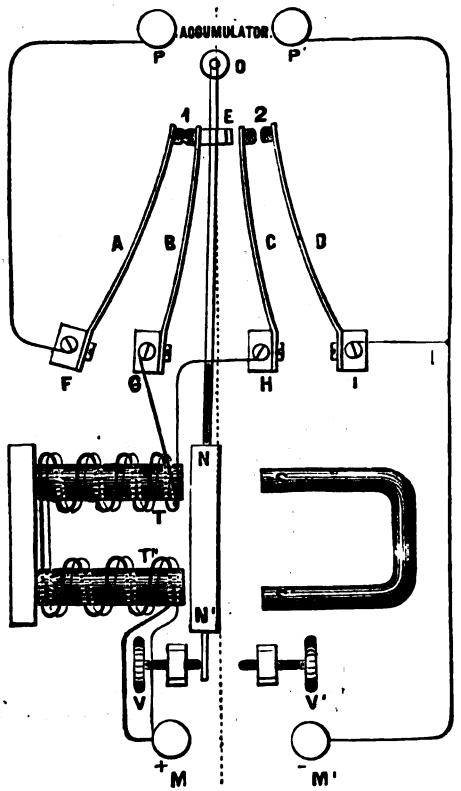


Fig. 422.—Hospitalier's Battery Charger.

secondary battery at P, leaving it at P′, and back again to the machine through M′. It is clear that by this arrangement the secondary battery is put out of the circuit whenever the current diminishes beyond a certain limit; and is inserted again when the required strength is reached. If a strong current is required the screws V and V′ are so arranged as to allow the armature N N′ to approach very near to S S′. As the force of attraction of the magnet diminishes with the distance, the change will be in favour of the magnet S S′, and the electro-magnet will now require greater force to attract the armature

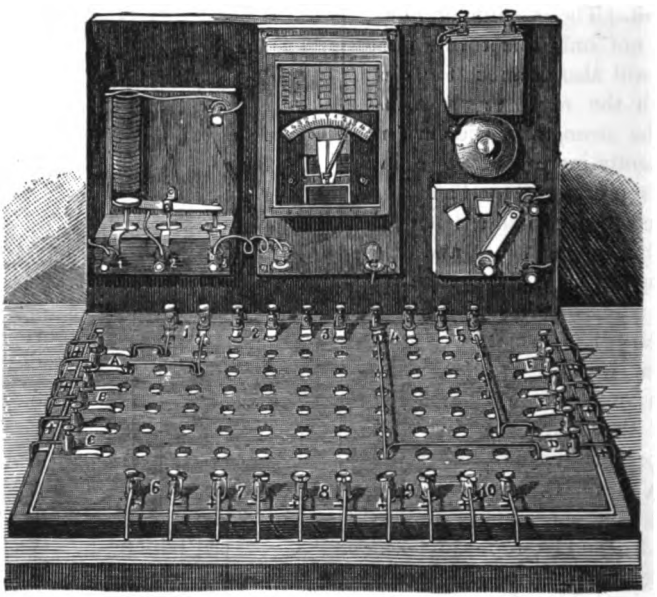


Fig. 423.—Kabath's Battery Charger.

to itself. The secondary elements will only remain in the circuit so long as the electro-magnet is sufficiently powerful to keep the armature N N′.

The apparatus used by Kabath for charging and discharging secondary elements is shown in Fig. 423. A series of holes are bored in a board, and are filled with mercury. The holes of the first and lowest row are connected with the clamps 1 to 10, with which the poles of the accumulators are connected by means of copper bands or wires, which dip into the mercury. The holes from A to D to the left and right are also connected with clamps which connect the poles of the machine charging the secondary elements, and also hold the wires of the lamps and motors to be supplied with current from the accumulators. The connection of one or more series of accumulators, etc., is brought about by using bent copper rods, the ends of which dip into

the respective holes. The automatic contact-breaker, consisting of an electro-magnet and armature, is fastened to the left. As long as the primary current has the required strength, the magnet attracts the armature, causing the metallic pin of the lever to dip into the mercury, connected with the screw 3. In this position of the lever the current can flow to screw 1, passing on its road screw 2, and the mercury belonging to it, through the right half of the lever, and then to screw 1, then through the galvanometer into the secondary elements. If the primary currents become too weak, the armature will fall away from the electro-magnet, and the pin on the left arm of the lever will dip into the mercury, whilst the pin on the right arm is lifted out, and contact between the primary current and the elements will then be broken. At the same time a bell arranged to the right will begin to ring, and will draw attention to the fact. The apparatus under the bell is for the purpose of readjustment.

Recent Improvements in Secondary Batteries.—The Electrical Power and Storage Company have recently so far improved their secondary batteries that they can now be relied on to render important service in the application and distribution of electricity. No doubt in what the Americans call "the electric boom of 1882," there appeared many extravagant statements of what secondary batteries might be expected to do, which have not been, and never can be realised; and much money was thrown away in the effort to make them serve purposes for which they are not suited. Now, however, there is no doubt that they are made, by several makers, of so good a construction that they can be used for years with good effect, if it be remembered under what circumstances it is an advantage to store energy even when there is a loss of 25 per cent. in doing so. When these accumulators are in circuit—in a lighting installation, for instance—(1) a break-down in the machinery does not interfere with the supply; (2) the steadiness of the supply does not depend on the speed of moving machinery; (3) the expensive engines and dynamos may pay interest for twenty-four hours a day, instead of only for the few hours the lights are going, being employed in charging the batteries when not required for lighting.

The latest improvements have been directed to the following ends:—First, to make the cell more durable, and more portable and convenient; secondly, to improve the plates, and so prepare them that there shall subsequently be no fluting or blistering; thirdly, to provide against possibility of injury by over-charging; fourthly, to reduce the resistance (now brought down to ·002 ohm); fifthly, to supply some automatic indicator which may work a switch to turn the current into the cells or off, according to the state of the charge.

The first three improvements have been carried very near to perfection by the best makers. The last has only partially succeeded. When the cells are all charged in parallel position, one cell (termed the master-cell) may work the indicator, but no thoroughly satisfactory master-cell has been devised for mixed methods of charging. The most promising system is one in which there are

several master-cells in each battery, all the master-cells having a combined action, and the state of each being shown by the specific gravity of the liquid. The function of the indicator and the switch attached to it is to cut out the dynamo and to switch in additional cells when the E. M. F. has become too high, and to re-connect with the dynamo and cut off the extra cells from the lamp circuit when the E. M. F. has fallen too low.

The cost of secondary batteries is great, but the saving in copper conductors and machinery which is effected by their use will often more than compensate. Fewer dynamos will be required with the battery, and a smaller size of conductors. Professor George Forbes has recently estimated the reduction of cost by using the dynamo to charge the battery when it is not wanted for lighting, at a third. His data are as follows:—The cost of batteries when charged from a dynamo is £3 per lamp of 60 watts; the cost of direct lighting, £1 per lamp. Suppose the direct and secondary methods to be combined, and suppose the dynamo to feed the batteries for six hours in the day time, and the lights for four hours at night. With this arrangement the number of lamps supplied will be double that of either source alone. Hence, the cost of half the number being £1 per lamp, and of the other half £3 per lamp, the average will be £2 per lamp. But the estimates depending on possible reductions vary so enormously that it is impossible to frame a general statement. We may, however, regard it as established, that in large districts there is economy in using secondary batteries, and in small districts there is economy in a service that is altogether direct. An important compensation for the extra cost is, however, to be found in the freedom from absolute dependence on the perfection of machinery, and may make it worth while to use the batteries, even at the greater cost, for the same reasons as often lead to a reduplication of parts of machinery. Moreover there are the cases in which direct service is not available, and for which the secondary batteries, charged at a distant station and transported bodily to the scene of action, are the readiest means of supply. For these reasons we may expect secondary batteries, in their improved form, to render important services in the future.

PART II.—DIVISION II.

PRACTICAL APPLICATIONS OF ELECTRICITY.

THE ELECTRIC LIGHT.

HISTORY OF ELECTRIC LIGHTING.

NOT taking into account natural phenomena, such as lightning and St. Elmo's fire, etc., the first experimenter who produced an electrical glow was Otto von Guericke. Neither the glow of electricity nor the electric spark, nor electrified gases and vapours in a rarefied condition, as in the electric egg and Geissler's tubes, have, however, been used for producing electric light for practical purposes; this was left to the voltaic arc on the one hand, and glow lamps on the other. Davy (1800), in a letter directed to Dr. Beddoe, mentions experiments in which electric sparks were obtained between two carbon points caused by a voltaic pile. In these and similar communications before 1808 no mention is made of an arc light. Davy showed the arc light for the first time in 1810 at the Royal Institution; and for this purpose he made use of a battery consisting of 2,000 elements. Foucault (1844), instead of using charcoal enclosed in a vacuum, as Davy did, made use of carbon from the retorts of gas works, which is much harder, and consequently not so soon consumed. Deleuil made use of Foucault's hand regulator to light the Place de la Concorde, Paris; it was placed on the knees of the allegoric statue of the town of Lille (Fig. 424).

Adjusting Apparatus.—Thomas Wright, London, devised the first apparatus (1845) in which the adjustment of the carbons is brought about automatically. W. C. Staite used the electric current for the regulation of the carbons in 1848. The apparatus represented in Fig. 425 is the regulator of Archereau, constructed in 1849 on the same principle as that by Staite and Perie. A B, C D, and A C consist of copper; *t* is the fixed positive carbon. The solenoid S is fastened between the rods E F and G H. To the rod J K is fastened the negative carbon *t'*. The current enters the solenoid through the positive wire, and leaves the apparatus at D. Foucault constructed in 1858 the apparatus shown in Fig. 426, taken from *La Lumière Électrique*. The two carbons *a* and *b* are arranged horizontally, fixed upon the rollers *c c'*. The two springs R R' tend to move the carbons towards each other, and are connected by means of a string running over the pulley P with it, so that the motion can take place

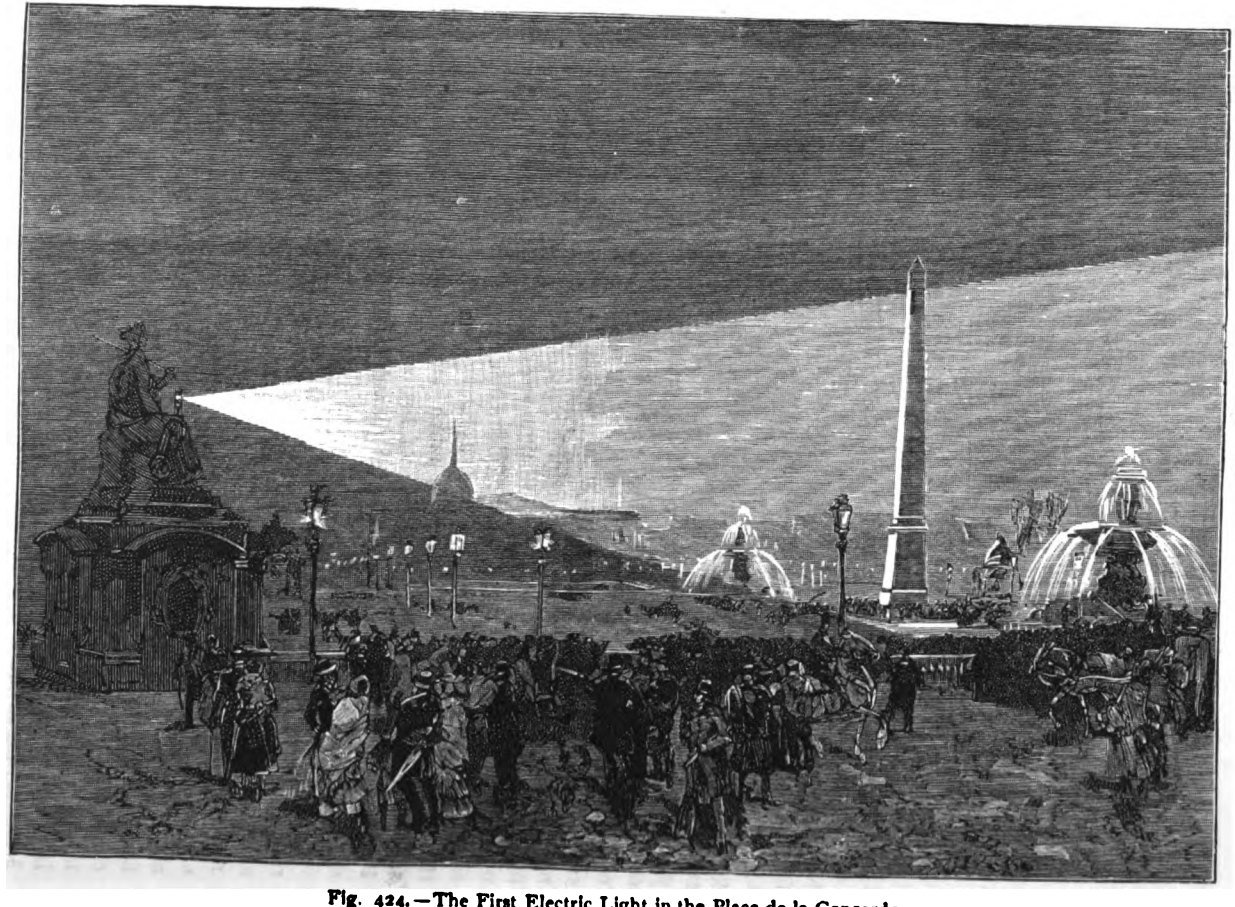


Fig. 424.—The First Electric Light in the Place de la Concorde.

only when the clockwork M also moves. The lever L and the string P' P'' P''' are so arranged that *c* and *c'* move at the same time, only *c'*, having the negative carbon, moves much more slowly than *c*. The electric current before it enters the carbons has to pass the electro-magnet E. To the armature A, which is movable about *r*, the rod D is fastened; and according to the position which the

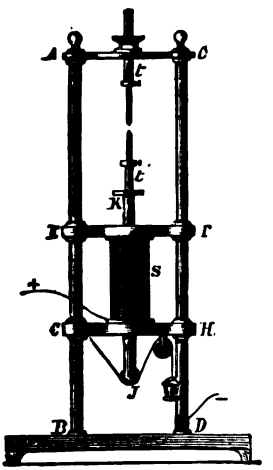


Fig. 425.—Archereau's Regulator.

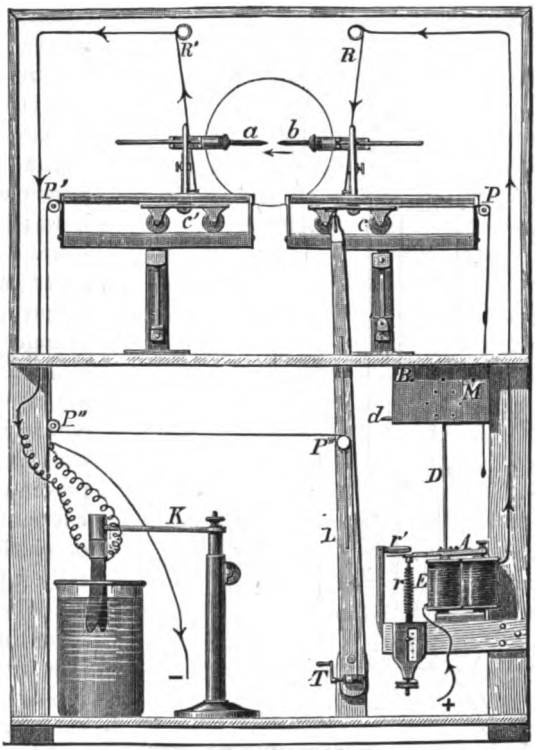


Fig. 426.—Foucault's Regulator.

armature has, it will liberate or stop the clockwork. The spring *r* tends to lift the armature from the electro-magnet. By means of the catch *d* the clockwork may be stopped by the hand. The voltameter K compensates for variations in the strength of current; increasing or diminishing the resistance by allowing the plates to take different positions in the fluid. When the carbons *a* and *b* are at the right distance from each other, the current will have its normal strength, and the electro-magnet attracts the armature A. In this position the rod D stops the clockwork, and the carbons remain stationary. If the distance of the carbons by means of their consumption becomes too large, *i.e.* increases the resistance in the circuit, the spring *r* overcomes the force of

attraction of the magnet E, and the armature A is lifted off; the rod D no longer stops the clockwork, and *c c'* can move towards each other until the resistance of the circuit has its original value, and the arc has its normal length. The current will then have its original strength, and cause the electro-magnet E to attract the armature A again.

Le Molt, Roberts, Slater and Watson, Christopher Binkes, and Chapman constructed improved apparatus which we shall consider farther on. The lamp constructed by Lacassagne and Thiers (1855), shown in Fig. 427, deserves notice: on the one hand, because it has a regulation on a hydrostatic principle; on the other hand, because it was the first so-called differential lamp. The carbon K is fixed and the lower carbon K' is pushed upwards by means of the mercury contained in the cylinder B B. To light the lamp when inserted in a circuit, the two carbons are moved asunder by the hand. The mercury of vessel A would push the carbons at once together, were it not prevented by a valve. The tube D D has another tube *e f*, the two divisions of which are connected by means of a short piece of india-rubber tubing at E. When the current goes through the lamp the electro-magnet C C attracts its armature I, which squeezes the india-rubber tube together, preventing the mercury from entering the cylinder B B. The electro-magnet H is in shunt to the main circuit, and has but little power as long as the current has its normal strength, *i.e.* as long as the resistance in the main circuit remains normal. The strength of the current in the shunt circuit will increase with the increase of resistance in the main circuit, *i.e.* proportionately to the burning away of the carbons. As soon as the force of the electro-magnet H has become greater than that of the magnet *c c*, it will attract the armature I in its turn; this will relieve the tube E of pressure, and the mercury can then flow from A to B B, and raise the carbon K' until the normal length of the arc is again obtained, when the electro-magnet *c c* will be powerful enough to stop the motion. The motion of the carbon K' is regulated by the different effects of the two electro-magnets C and H. This apparatus answered

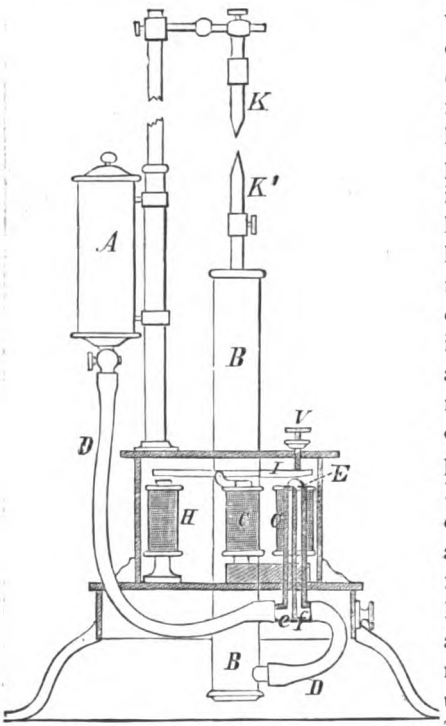


Fig. 427.—Lacassagne-Thiers' Lamp.

very well, and both Lacassagne and Thiers made use of it on different occasions.

Serrin constructed his lamp in 1857, and nothing but the high cost at which electricity could be generated stood in the way of using it for lighting on a larger scale. With the invention of the Pacinotti-Gramme ring and the utilisation of the dynamical principle, generators of electricity were obtained which furnished powerful electric currents at a comparatively moderate price, and the improvements in the lamps kept pace with the other inventions. To make use of the electric light on a larger scale, however, the problem of dividing the electric light had yet to be solved.

Paul Jablochkoff.—The first step towards the division of the electric light was made by Paul Jablochkoff (1876), by the invention of the electric candle bearing his name. Paul Jablochkoff was born at Serdobek (1847); he received a careful education, and finished his studies at St. Petersburg. In 1871 he was appointed director of the telegraph lines between Moscow and Kursk. In spite of highly flattering offers which the Russian Government made, he resigned his post in 1875, anxious to devote his whole time to private studies. He intended to see the Exhibition of Philadelphia (1876); his journey, however, found its end at Paris, where he became acquainted with Breguet, who placed his laboratory at Jablochkoff's disposal, and introduced him to his friends, aiding him as much as possible. Owing to this kind reception and encouragement, Jablochkoff, after a stay of eight months, invented his candle. The invention of the electric candle caused a great sensation. In 1881 about 4,000 lamps with Jablochkoff's candles were in use; but as their use increased their defects were found out. Regulated lamps were again brought into use, and with them experimenters again endeavoured to solve the problem of dividing the electric light.

The several parts of a circuit, as we know, may be arranged either in series or parallel. Let us first consider in what manner the current has to branch off to make the different lamps independent of each other when joined in series. The circuit s s (Fig. 428) divides at *a* into two branches, which unite again at *b*, then again branch off at *c*, and unite at *d*. By this arrangement the currents in the branches s_1 and s_4 must be to each other inversely as the resistances of these branches, and the sum of the currents of both branches will be equal to the strength of current in the undivided circuit s. The same holds good for the branches s_2 s_3, or any similar pair. If lamps are inserted in this circuit so that their carbons are in s_1 or s_3, but their regulation mechanism is worked by s_4 or s_2, the problem of division by branching is solved, for the system works as follows: When the current divides at *a* the larger portion goes through s_1, because here, as long as the two carbons touch each other, the resistance is but small; s_4, however, is a spiral of high resistance. When, now, the carbons are separated and the arc formed, the resistance in s_1 is increased, and increases through the burning away of the carbons until the stronger portion of the current will flow through s_4 and the weaker through s_1. This brings the regulating mechanism into operation,

and the carbons are brought near each other again. The regulation of the lamp takes place between the points *a* and *b*, and the strength of the current also changes in the branches between these points only. The strength of current in the undivided circuit remains unaltered; hence, if now between *c* and *d* a second lamp be inserted, it will be entirely independent of the first lamp and of the regulations and fluctuations of current combined with it. The first lamp constructed on this shunt-regulator principle was that of Lacassagne and Thiers, already described. As the lamp was neither constructed nor used for the division of light, priority in the discovery of a solution of the problem of division of light is due to Tschikoleff, who exhibited lamps so arranged in 1877.

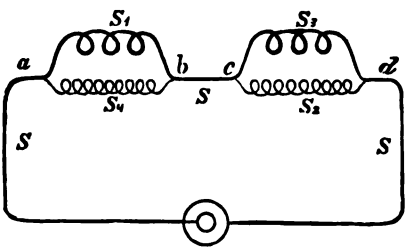


Fig. 428.—Series Arrangement.

The mode of conducting the current above described is mostly used for arc lamps. When glow lamps are used the parallel arc system answers better (Fig. 429). Here the current passes the different lamps at the same time, whilst in the former system the current passes one lamp after the other. The lamps are in parallel or divided circuit, instead of being in series. To distribute the current with glow lamps joined parallel, we have already found the best method to be that of using compound machines.

The History of Incandescent Lamps.—Although only quite recently glow lamps have been constructed in such forms and with such qualities as to answer practical purposes, attempts to produce them were made some years ago. Jobart proposed (1858) to make use of a small carbon in a vacuum. F. Moleyns, of Cheltenham, took out a patent for a lamp, which had a glowing platinum spiral upon which coal-dust was allowed to fall. Du Moncel (1859) obtained very good results by experimenting with carbon filaments of cork, sheepskin, etc. Konn took out a patent for the lamp shown in Fig. 430. By means of the screw L and india-rubber discs a glass globe is fixed air-tight to the copper socket A. To A two copper tubes are attached; one of them D carries the plate G; the second tube has the movable rod C and the disc F and lid J. The tube D is insulated, and is connected with the insulated screw N. The other tube is not insulated. At K is a valve which only opens outwards. Between two disc-shaped plates F and G the five couples O are fixed, each of them having a carbon rod E. The upper ends of the carbon rods are unequal, so that the lid rests only upon one carbon

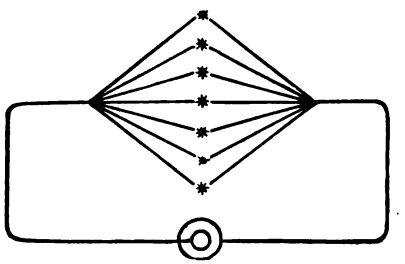


Fig. 429.—Parallel Arrangement.

at a time. The vessel is exhausted before use is made of the lamp. The current enters through the clamp N, passes D and G, and enters one of the carbons E. It then flows through I and C into the socket A, leaving the lamp through a second clamp not drawn in the figure. The carbon rod becomes white-hot, giving a steady and quiet light. When the cross section of the burning carbon is so hot as to break, the lid J falls upon the next carbon, and brings it into the circuit. To prevent glowing pieces of carbon from falling upon the glass, the copper cylinder M is introduced. Between the years 1877 and 1880 glow lamps were much improved by Swan, Maxim, Lane-Fox, and Edison;* the latter especially drew attention to his system of lighting at the Exhibition of Paris, 1881.

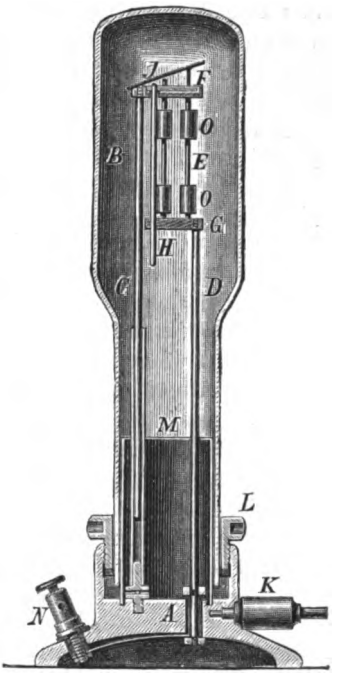


Fig. 430.—Konn's Lamp.

General Features and Classification of Electric Lamps.—For the production of the electric light two methods are made use of at present. One method is to produce the voltaic arc, the other to utilise the electric current by causing it to bring substances of high resistance, such as carbon, to a white heat. In all cases, to produce electric

* As the career of Thomas Alva Edison has been in many respects a most remarkable one, it may interest our readers if we give a few details respecting it:—He was born in 1847, on the 10th of February, at Milan, in the State of Ohio. He passed his childhood at Port Huron, in Michigan. His mother taught him reading, writing, and arithmetic; but his further education he obtained by private study, without any help or assistance whatever. Owing to the straitened circumstances of his parents, he began to earn his livelihood at the age of twelve as "train boy," a kind of travelling porter, on the line between Canada and Central Michigan. Whenever his duties allowed, he employed himself in his luggage van in reading and studying books which he bought with his earnings. Amongst other books he came across was R. Fresenius' "Qualitative Analysis." He made himself perfectly master of its contents, and, thanks to his iron will, overcame the difficulties which were placed in his way, by fitting up a laboratory in his luggage van, where he experimented during his journeys. Entering on one occasion the office of the *Detroit Free Press*, he observed that worn-out type was just then being offered for sale. He bought the most necessary appliances, and a few days after he published the *Grand Trunk Herald*, of which he was the editor. This paper he offered for sale to his passengers. The undertaking, however, came to a sudden end; a bottle containing phosphorus fell down, and caused a fire in the luggage van. Although the guard and Edison extinguished it at once, the former, to prevent similar accidents, threw the whole of Edison's materials out of the window. His second journalistic attempt, under the title of *Paul Pry*, also came to a sudden end. All contributors, as long as they did not claim payment, were welcomed by Edison. It happened, as a consequence, that private individuals and public institutions were sometimes attacked by his paper, in anonymous contributions. One morning Edison happened to meet an inhabitant who had been violently attacked by his paper that same morning, and the latter, without further preliminaries, took Edison by the collar and pitched him into the water. Edison saved himself by swimming, but *Paul Pry* no longer appeared. Time was always of value to him, and to gain the twenty minutes which he required at first

light, electric energy has to be converted into heat. We have already had under consideration the laws according to which the conversion takes place. To use electricity for lighting purposes it is necessary to distribute the resistances in the circuit, so that the current finds a great resistance in the lamps, but only a slight amount in the remainder of the circuit. If attention be paid to this, the electric current will be converted almost completely into light, and the loss caused by heating the wires, reduced to a minimum. The theoretic principles have been brought into the following practical forms:

1. At that point of the circuit at which light is to be produced, a conductor of great resistance is placed, and is brought to a white heat by the passing current.
2. When the arc principle is used the circuit is broken at the particular point where light is to be produced, and one of the two ends is always a carbon rod, having a small cross section. These ends are made to touch each other but slightly, so that at the point of contact they offer the current a considerable resistance. If the carbon rod is in connection with the positive pole of the source of electricity, it will begin to glow when touched by the other end of the circuit, and as the intensity of the glow increases, will produce a powerful light.
3. All lamps use the principle of the production of light by concentrating *resistance*, no matter what their construction may be.

Lamps, therefore, may be conveniently divided into the following groups:

The first group comprises all those lamps depending on the use of a bad conductor in an uninterrupted circuit, to produce the glow. To the second group belong those lamps which produce a great resistance to the current at a particular point, by means of the incomplete contact of the electrodes. The light of these lamps is a combination of incandescent and arc light, composed of the glowing of the carbon, and minute voltaic arcs, formed between the irregularities of the electrodes, which touch each other.

to walk from the station to his home, he heaped some sand at the back of his house, which stood close to the line, and on this sand-hill he alighted as the train passed. His saving a child from death led to his learning telegraphy. Edison, standing on the platform of Port Ellmont, observed a child playing on the rails in front of an approaching train. Edison, without hesitating a moment, jumped off the platform and snatched up the child. The engine grazed Edison's body, but he was only slightly injured, and fell down at the other side of the rails with the rescued child in his arms. The father of the child, the station-master of Port Ellmont, whose acquaintance he thus made, instructed Edison systematically in telegraphy. Edison then left his post as "train boy," and devoted his time to telegraphy. It was not very long before he not only surpassed all his colleagues in his skill and speed of working, but also made invention after invention. To mention them all would lead us beyond our limits. For improvements in connection with the Morse apparatus alone, Edison possessed, in 1881, thirty-six patents. He left the telegraph service, and fitted a large laboratory at Menlo Park, near New York, where he made his greater inventions, as, for instance, the phonograph. To complete this brief sketch of a very remarkable man, it may be added that he is as much esteemed in social and domestic life by those who know him intimately, as he is appreciated by the world at large as a great inventor.

Lamps producing the voltaic arc may be divided into three groups. To the first group belong those lamps which have the relative positions of their carbons regulated, by means of some contrivance, according to the strength of the current; and to the remaining two groups belong all lamps in which the carbons remain unaltered as long as the arc is glowing. The constancy of the length of the arc is, as Uppenborn expresses it, effected by the geometrical construction of the lamp.

Lamps belonging to the last two groups are divided into two classes, as their carbons are parallel to each other or opposite to each other. The five groups are therefore as follows:

1. Glow lamps or incandescent lamps, in which the light is produced by means of a bad conductor in an uninterrupted circuit, the conductor not being subject to a regular combustion.
2. Mixed or semi-incandescence lamps, half glow and half arc. This light is produced at the place of contact between two conductors; one of them being consumed more or less quickly.
3. Regulated lamps. The light is formed by means of the voltaic arc, and the distance of the carbons is continually regulated by clock-work or other means, according to the strength of the current and rate of wearing of the carbon.
4. Electric candles. This light is also produced by the voltaic arc, but the distance of the carbons from each other during burning is not altered, and the carbons are parallel to each other.
5. Lamps having their carbons opposite to each other, the light produced being that of the ordinary voltaic arc.

GLOW OR INCANDESCENT LAMPS.

Edison's Glow Lamp.—The first glow lamp which T. A. Edison constructed had platinum wire, similar to the one devised by Changy. Edison examined the properties of many organic and inorganic substances, with a view of finding the best substance for the filament, and fixed finally upon bamboo fibre.

By means of machinery the bamboo is divided into fibres of 1 millimetre in diameter, and 12 centimetres in length. These fibres are pressed into U-shaped moulds, which are put by thousands into ovens, where they are allowed to become carbonised. The carbon filament is attached to platinum wires, which are fused in a glass vessel having the form shown in Fig. 431. The vessels are exhausted by air-pumps, constructed by Edison for the purpose. During exhaustion an electric current is sent through the carbon filament, for the purpose of driving off any gases which might have been absorbed by the carbon. To prevent the platinum wires from melting at high temperature,

the carbon filaments are considerably thicker at the end connected with the platinum wires, so as to offer less resistance to the current. The free ends (Fig. 432) of the platinum wires are connected with the copper sockets D and E, which are insulated from each other by plaster of Paris. F and C are copper pieces which are separated by the disc L, consisting of insulating material

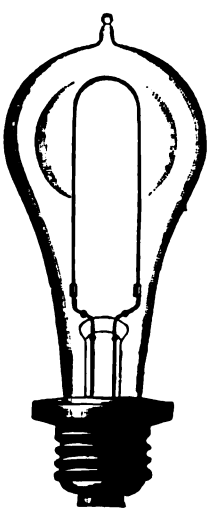


Fig. 431.—Edison's Lamp.

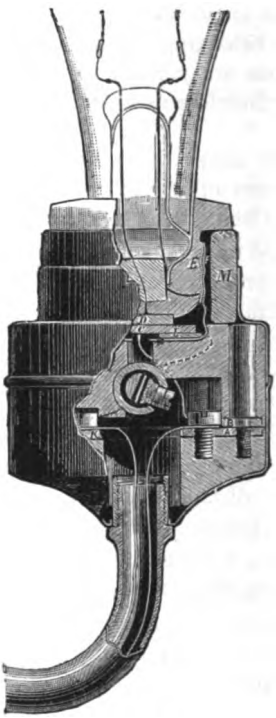


Fig. 432.—Edison's Lamp Fitting.

M is a wooden ring serving to insulate the different metal plates from each other. By screwing in a lamp contact is made between E and F, and between the plates C and D at the same time. By means of the plates B J and A K, which touch each other, contact is made within the wooden ring. This ring consists of two portions covered with sheet brass. The first portion of the wooden ring is connected with the wires leading from C and F. Wires from the circuit are pressed by means of screws against the plates A and K.

Fig. 433 represents the key for turning the lamps on and off. The wire leading from F (Fig. 432) is divided in the middle, one portion leading from F to G, the other from H to I (Fig. 433). As the two plates G and H are

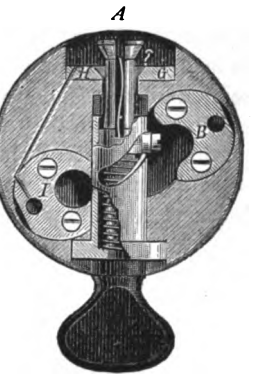


Fig. 433.—Edison's Key.

insulated from each other, contact must be made to allow the current to pass when the lamp is to be lighted. It is made by the cone at the end of the screw or axis of the key. By breaking contact the light is put out. To give an end-way motion of the key, when turned either way, the central axis has a projecting pin, working in a spiral slot, as shown in Fig. 433. By turning the key one way, the cone of the key A comes between the plates H and G; and by turning it the other, the cone is forced above these. When contact is made between the plates G and H by means of the cone, the current flows through the wire (Fig. 432) to disc A, then through B, C, D into the lamp, flowing through the carbon filament and then to E; from here the current flows to G, and through the cone to H, leaving the lamp by means of the wire H I and the plate K.

The following table gives intensity, resistance, and E. M. F. of lamps in practical use:

	Intensity.	Resistance.	Electromotive Force.
A Lamp	16 candles	140 ohms	103 volts
,,	32 ,,	70 ,,	103 ,,
B Lamp	8 ,,	70 ,,	56 ,,
,,	10 ,,	250 ,,	103 ,,

Fig. 434 represents an arm having joints at A, B, and C. Fig. 435 shows the arrangement of the joints A and B. At C (Fig. 434) is a key constructed as

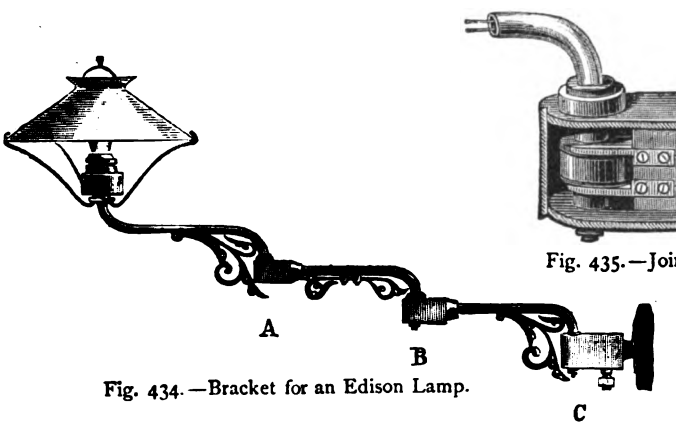


Fig. 434.—Bracket for an Edison Lamp.

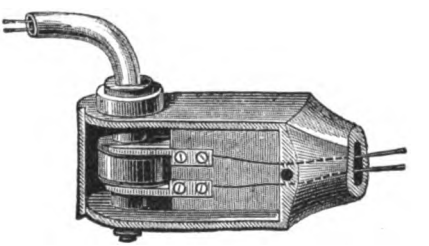


Fig. 435.—Joint of Bracket.

described above; a short portion of the wire leading into this joint is made of lead, to prevent the destruction of the carbon filament in the lamp. The cross section of the leaden wire is such, that should the strength of current increase beyond a certain limit it will become heated and melt off, thus breaking contact.

Edison's Regulator.—Edison further constructed a lamp with a regulator, by means of which the intensity of the light may be varied as desired. Fig. 436 represents the portable lamp, and Fig. 437 the regulator of it. The

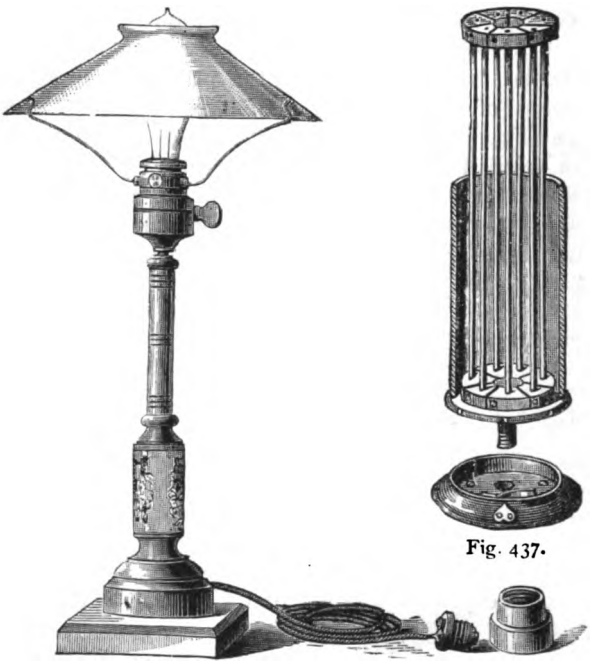


Fig. 437.

Fig. 436.—Portable Lamp and Regulator.

latter is a kind of carbon rheostat, consisting of carbon rods of different diameters. The length and substance being the same, the resistance of these rods must be different; and by inserting one or other of the rods into the circuit the desired intensity is obtained. To prevent the apparatus becoming heated, the cylinder which surrounds it has openings allowing air currents to pass through. Regulation is brought about by means of the disc, which is drawn separately at the bottom of the figure, and by means of which contact is made with different carbon rods. An index on the disc and a graduation at the lower edge of the cylinder give the degree of intensity of the lamp for the insertion of each carbon rod.

Fig. 438 represents a lamp used in mines. The lamp is placed *in*

a vessel containing water. The connection of the conducting wires is so arranged that their points of contact are under water, therefore all risk of explosion by means of the lamp is avoided. The danger of suffocation is, of course, not avoided, as there is nothing to indicate the presence of noxious gases in the mine by the lamp.

From the foregoing description it may be seen that Edison's lamp is well considered in all its details, and combines with the advantages of electric lighting the convenience of gas-light, without its drawbacks and dangers. Each lamp is guaranteed to burn 800 hours; after about that period the lamp perishes;

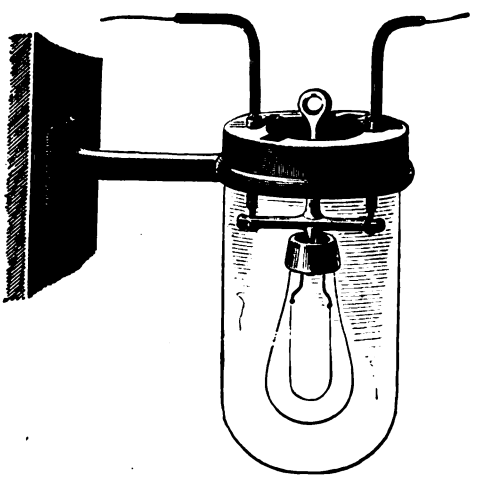


Fig. 438.—The Miner's Lamp.

but taking into consideration the low price of each, and that with most other systems of lighting the cost of fittings is unavoidable, this can hardly be considered an obstacle, or prevent the lamp from being extensively used for practical purposes.

Swan's Glow Lamp.—Swan has done much towards the perfection of glow lamps. Long before Edison, he tried to obtain more durable carbon filaments. Too little attention had been paid by other experimenters to the exhaustion of the vessel containing the carbon, and also to the diminution of resistance at the ends of the carbon connected with the platinum wire. Fig. 439 shows a lamp by Swan. The platinum wires are carefully fused into a little glass tube ending in two loops outside. The lower portion consists of gutta-percha which has a glass screw, by means of which the lamp might be screwed upon any ordinary gas-arm after removal of the burner. Each of the platinum hooks is connected with one of the keys. The carbon is ten centimetres long, and is prepared from cotton fibres soaked in sulphuric acid (2 parts acid to 1 part water); they undergo a similar change to paper when similarly

treated, *i.e.* artificial parchment is obtained. The fibre, which after the treatment is more tenacious, is bent into the form required, and is placed in a crucible filled with fine coal-dust, hermetically closed and exposed to heat. The carbons are fastened to the platinum wires in the following manner: Their ends are made to overlap, and are bound together by cotton, which again is carbonised.

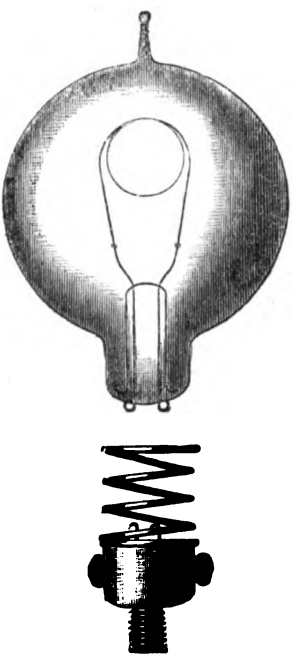


Fig. 439.—The Swan Lamp.

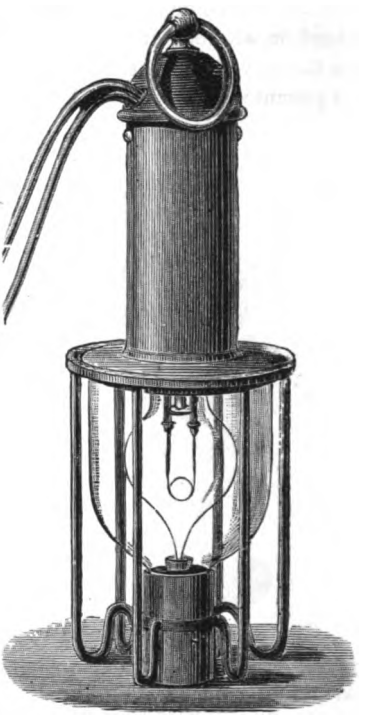


Fig. 440.—The Miner's Swan Lamp.

The following is a table of these lamps, showing the resistance for particular strength of current and E. M. F. :

Class.	Volts.	Amperes.	Ohms, cold.	Ohms, heated condition by calculation.	Candles.
A_3	36	1·422	36	25·31	16
A_1	41	1·28	53	32·03	18
B_1	46	1·32	54	34·84	20
C	50	1·343	65	37·23	20
D	52	1·235	74	42·1	20
E	54	1·21	82	44·63	20

The lamp shown in Fig. 440 is intended for mines.

Maxim's Glow Lamps (Fig. 441).—The carbon B, of gridiron shape, is carried by the two platinum wires C D and C_1 D_1, which are fused into the glass at D D_1. The glass tubes D D_1 are conically shaped, so that very small intervals between the glass and wires may be obtained. The mode of fastening the carbon to the platinum wires at C C_1 is shown in Fig. 442 (side view). To the wire a little plate *b* is soldered with gold, after that comes a plate of soft carbon S, then the

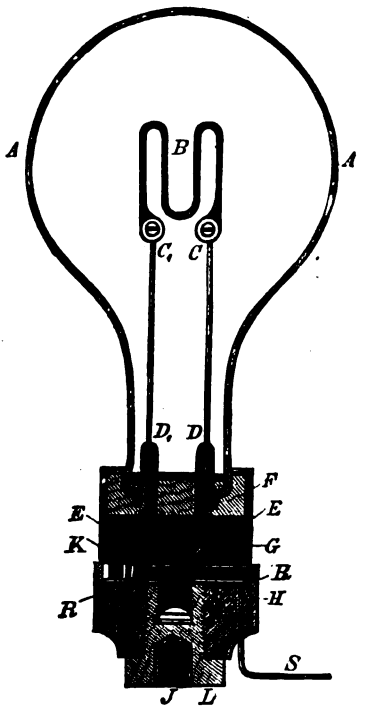


Fig. 441.—The Maxim Lamp.

Fig. 442.

carbon B, then a soft carbon plate S_1, and last a platinum plate b_1. All these parts are held together by the screw *o t*. The glass vessel A is fastened into the metal ring E by means of plaster of Paris F, which also enters the tubes D D_1. Owing to the difference of the co-efficients of expansion of glass and platinum, fractures were frequently made through which the air could pass. To prevent this as much as possible, Maxim divides the platinum wire into fibres, and fuses each platinum fibre into the glass separately. These fibres are again united. G is a layer of shellac, or some similar substance, to insure an air-tight fit. The base of the lamp H consists of vulcanite, or other insulating material, screwed to the metal piece L. The platinum wire on one side C goes to the metal screw L,

whilst on the other side C_1 it ends in the metal piece K, which is insulated from its base. R is a metal ring, the upper surface of which lies directly under K, and makes contact with it when the base H is screwed down. The current enters C_1 through the wire S, which is soldered to the ring R, and leaves the lamp at C by means of L, with which a second wire is connected; or where the lamps are fastened to gas-arms, by means of the support.

Maxim prepares the carbon for these lamps from Bristol paper. An **M**-shaped piece of paper is first cut, and then partly carbonised. This is fastened to the

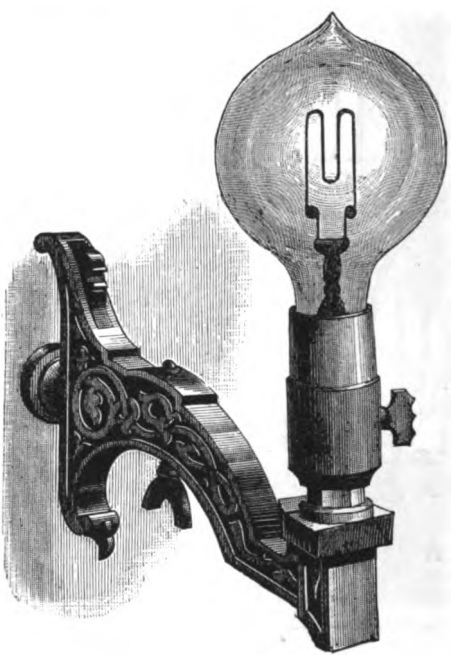


Fig. 443.—Maxim Bracket.

platinum wires and placed in the vessel A. The air in the vessel is exhausted, and then gasoline vapours are allowed to enter; these are again subjected to a pressure of about 30 millimetres, and the partly carbonised paper is inserted into a circuit. The electric current decomposes the gasoline, and deposits minute particles of carbon in the pores of the paper. It is a matter of importance that the latter shall be made to glow strongly, and to rarify the gasoline vapours. Without this rarification, carbon is too quickly separated out and adheres to the surface of the paper only. To obtain carbons having the same resistance, and so producing lamps of the same intensity, Maxim inserts a standard lamp into the circuit, and allows the carbon to be deposited until both lamps have the same

intensity. The glass vessel is then exhausted as perfectly as possible, and the lamp fitted in the way we have described. Fig. 443 represents a lamp by Maxim, fitted upon a bracket. The carbon of the Maxim lamp has, when cold, a resistance of 73 ohms, and when hot 39 ohms. It requires an E. M F. of 48 volts by 1·25 amperes. The intensity of its light is equal to that of 14·6 standard candles. In order that accident or damage to one part may not necessitate the throwing away of the whole lamp, Maxim has recently modified the forms both of his carbons and glass vessels.

Glow Lamps by Lane-Fox (Fig. 444).—Two wires *e e*, which are connected with the mercury tubes *f*, are attached to the metal springs *c*, which

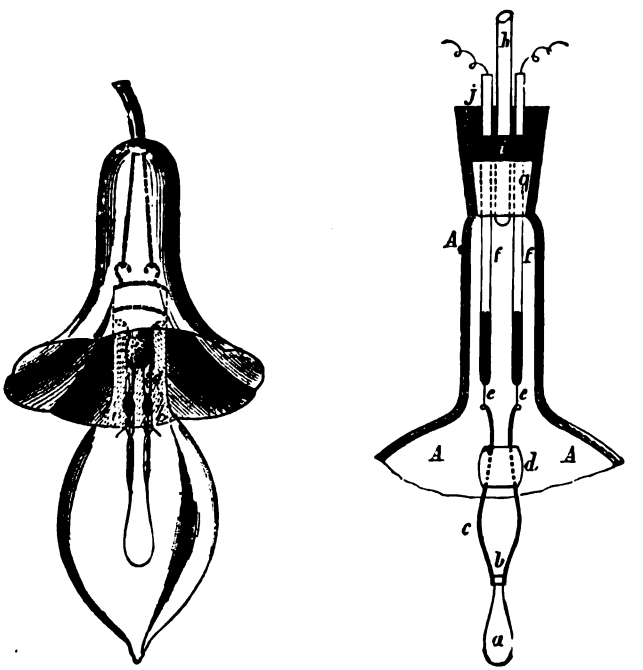


Fig. 444.—The Lane-Fox Lamp.

are the carbon holders. These springs are regulated by the slide *d*, consisting of insulating material. The tubes *f* and *h* pass through an india-rubber cork *g*; *i* is a layer of mercury, and over it is a layer of cement *j*. The glass vessel is exhausted by means of the tube *h*.

Lane-Fox prepares the carbon filaments for his lamps in the following manner: Hemp threads are wound round a piece of coke having a knife-edge at one side; and the whole is placed in an oven. During carbonisation the threads contract and are cut by the knife-edge. In this manner carbons of the same length are

obtained. Benzole, or similar vapour, is used for carbonising the filaments, whilst the carbons are made white-hot by means of the electric current. The ends of the filaments are connected with a short piece of wire (short-circuited), and again a current passes through them. The lamp is constructed in different sizes, and for an intensity of 8·7 candles, 66 volts by 0·673 ampere are required.

Siemens' Glow Lamps.—Siemens Brothers, of Charlottenburg, near Berlin, construct two kinds of glow lamps (Fig. 445, A and B). Wires having a cross section of 0·67 millimetre are used, and are fused into the glass at *f*. The space between *f* and *c c'* is filled with plaster of Paris; *a* and *b*

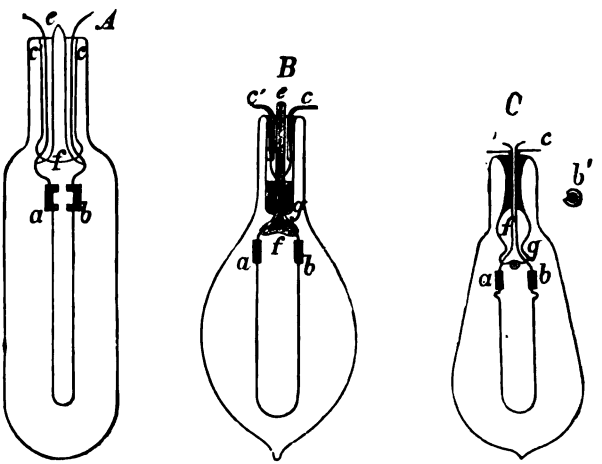


Fig. 445.—Siemens' Glow Lamps.

are clamps of sheet copper, by means of which the carbons are fastened to the wires. The carbons are produced from cotton fibres made thicker at their ends. The vessel is exhausted by means of the tube *e f*, which is then sealed. From four to seven platinum wires of 0·10 millimetre section are fused in the glass tube *e f* (Fig. 445, B), according to the intensity of the light required. The platinum wires lead to copper wires, which are soldered to the brass contacts at *c c'*. Within the vessel the ends of the platinum wires are fastened round the thick portions *a b* of the carbons. The space at *g* is filled with powdered mica covered with plaster of Paris. This powdered mica keeps away heat from the junctions.

Each of the lamps described requires a current of from 100 to 105 volts. Fig. 445, C, represents another glow lamp by Siemens and Halske. *a* and *b* are copper sockets for holding the carbon, the cross section being of the shape drawn at *b'*. The space *g f* is filled, as before, with powdered mica, having a layer of plaster of Paris on the top of it. At *c c*[1] the copper wires touch the contact

plates. Lamps resembling more or less minutely those already described are constructed by Müller, Grenier and Friedrichs, Brush, and others.

Cruto's Lamp.—The lamp by Cruto, represented in Fig. 446, was first used during the Exhibition at Munich. The carbon of this lamp is made in the following manner: A fine platinum wire is maintained at red heat by the electric current in an atmosphere of hydro-carbons, which is decomposed, its carbon being deposited on the platinum wire. The platinum is then volatilised by increasing

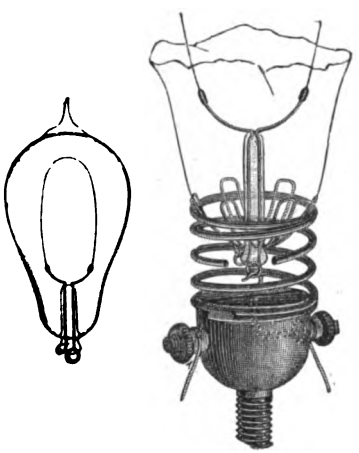


Fig. 446.—Cruto's Lamp.

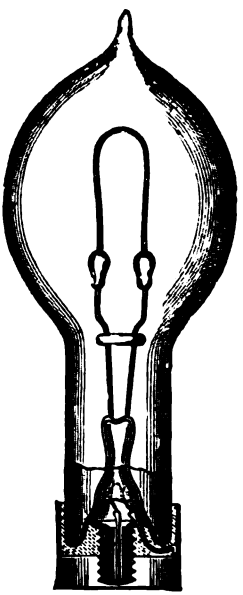


Fig. 447.—Bernstein's Lamp.

the current, and thus a hollow carbon filament is produced. At first the form of a spiral was given to the carbon; the more recently constructed lamps, however, have the usual horse-shoe filaments. Lamps of 4, 8, and 16 candles, with one and with two carbons, are constructed in this way, and the following figures respecting the current which feeds them have been determined by experiment (*La Lumière Électrique*):

	Candles.	Volts.	Amperes.	Intensity of Light in Carcel Burners.
Lamp	16 ...	58 ...	0·80 ...	2·06
,, ...	8 ...	36 ...	0·80 ...	0·91
,, ...	4 ...	21 ...	0·87 ...	0·79

The Boston or Bernstein Lamp differs in principle and in form from other glow lamps. By giving greater length and reducing the cross section of the carbon filaments in other lamps a high resistance is obtained, and the lamps must

therefore be joined parallel; but the Boston lamps, owing to the construction of their carbons, can be joined in series. The carbon for the lamp is produced in the following manner: Silk tubes, or tubes consisting of a similar material, are covered with paste and allowed to dry. They are then carbonised in iron boxes containing graphite or coal-dust. The carbons are fastened to the wires by means of a paste consisting of coal-dust and cement. This mixture becomes very hard, and makes a good connection between the carbon and the conducting wires.

Measurements made during the Exhibition at Vienna showed that the 50-candle lamp required a current of 5·39 amperes and 28·387 volts (*i.e.* 151 volt-amperes). With the Boston lamp a light of 292 candles can be obtained per horse-power, whereas the measurements made during the Exhibition at Munich gave for Edison's lamp only 186, for the Swan lamp 180, and the Maxim lamp 109 candles per horse-power.

Böhm's Lamp.—Böhm constructed his lamp with a view of saving the glass vessel when the carbon had become useless (Fig. 448). *r* is a tube for exhausting the glass vessel *g g*. The well-ground stopper has a groove cut in it at *c* to correspond with the tube *r*. After the vessel has been exhausted the stopper need only be turned to prevent the air from entering. The wires with the carbon are fused into the portion s s of the stopper. To replace a worn-out carbon filament the stopper is simply taken out, and a new carbon fixed to the wires.

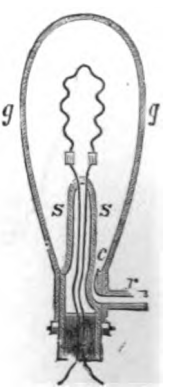


Fig. 448.—Böhm's Lamp.

Diehl's Lamp.—The chief difficulty in the construction of glow lamps is to fuse the wires so as to leave no places in the glass vessel which will allow air to enter. Diehl in constructing his lamp avoids this difficulty by having no wires at all fused into the glass. The glass bulb of the lamp (Fig. 449) consists of two tubes *g g* and G G, closed at their upper ends, their other or free ends being fused together. The inner tube is surrounded by insulated wire *d d*, the ends of which are joined to the carbon B. Inside the inner tube there is an iron rod E having a few turns of thick wire round it. The ends of this wire lead to the clamps P P_1. When alternating currents are used for this lamp, as they flow through the turns of the thick wire, they cause in the thin

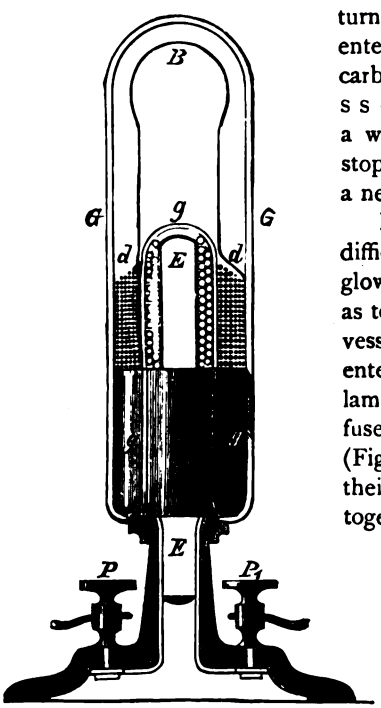


Fig. 449.—Diehl's Lamp.

wires *d d* induced currents, which bring the carbon to a glow. When continuous currents are to be used, a self-acting commutator has to be inserted. This lamp is much more expensive than other glow lamps under equal conditions, as the current of the generator has to be converted into induced currents, and this conversion always involves loss of energy.

We shall consider next the modes of manufacturing the bulbs or glass vessels, etc. A description of the process has been given in *The Scientific American* (vol. xlviii.), and by the Hamond Electric Light and Power Supply Company. In the factory of the company an eight horse-power machine drives a Siemens and a Ferranti alternating generator, with two inducing machines. The Ferranti machine furnishes current for the lighting of the factory, for feeding the carbons during the process of exhaustion, and for experiments. The Siemens machine deposits the carbon for the carbon filaments. Twelve glass-blowing machines by Wright take up another floor, and are tended by boys of from fourteen to sixteen years of age, who also make the carbon filaments from a kind of grass fibre. The fibres are first carbonised, and then immersed in a liquid containing carbon, which is deposited in the pores of the filament. This process gives it a metallic action and flexibility. The resistance is ascertained by means of Wheatstone's bridge.

Method of Fitting the Bulbs.—The process of fitting the bulb is shown in Fig. 450. The platinum wires to which the carbon loop is attached are

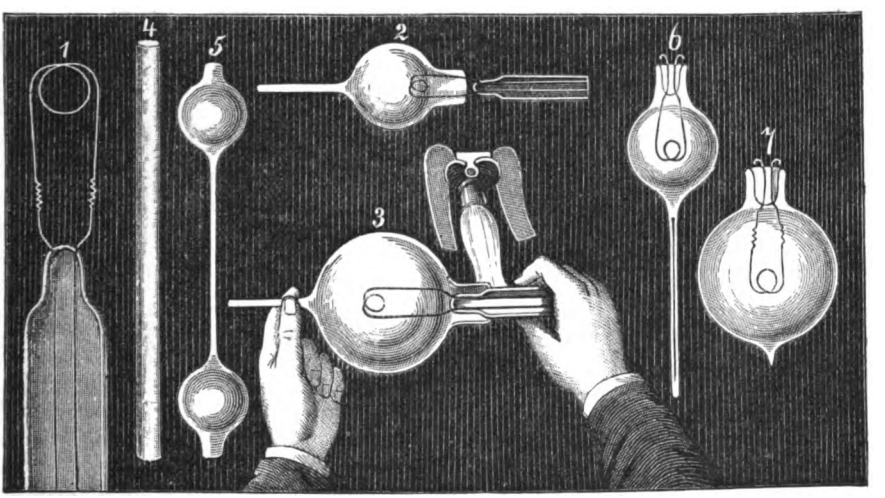


Fig. 450.—Stages in the Making of Incandescent Lamps.

fused into the glass stopper, as shown in 1. A glass tube of 230 millimetres in length and 20 millimetres in diameter (see 4) is drawn out and blown into bulbs, as at 5. The stopper (1) is then placed in one of these bulbs (2), and

the stopper and bulb are fused together (3). The lamp then has the form represented in Fig. 450 (6). After the bulb is exhausted the long tube at the apex is fused off, and the lamp then appears as at 7.

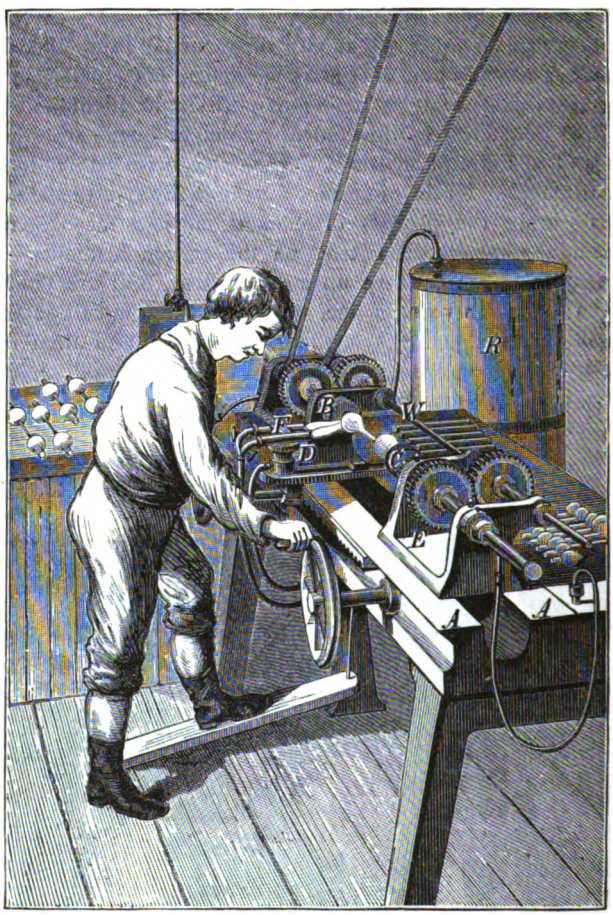


Fig. 451.—The Glass-blowing Machine.

The glass-blowing machine is shown in Fig. 451. It consists of a horizontal board A. D is fixed, E movable. Through these, hollow shafts, which have screws B C at their opposite ends, are carried. The two shafts are driven by a third shaft W. R is a reservoir of compressed air, from which the blast is forced into the hollow shafts, and from thence air enters the glass tube, which is held in a blow-pipe flame, and is turned continually. From 250 to 300 globes may be

turned out by a single boy per day. When the lamp has arrived at the stage represented in Fig. 450 (6), it is removed to another floor to be exhausted by the mercury air-pumps.

We cannot produce the necessary vacuum by means of an ordinary air-pump, for even the best constructed of these will not produce a greater exhaustion than will exert a pressure of about two millimetres of mercury. The vacuum for the glow lamp is produced by means of a kind of mercury pump in one of two ways.

The apparatus constructed by Geissler, and, as modified by Töpler, used by the Hamond Electric Light Company, applies the principle of the barometer. Imagine the Torricellian vacuum to be obtained not by filling the tube and inverting it, as shown in Fig. 452, but by closing the top of a tube by a valve that will let air out, but not in, and connecting the bottom of the tube with the cistern of mercury by an elastic tube. Then on lifting the cistern to the level of the top of the tube the mercury would flow into the tube and drive out the air, and then on lowering the cistern to a distance of more than 760 millimetres, or 30 inches, the mercury would flow back to the cistern, and would leave a vacuum at the top of the tube. Fig. 453 represents two sets of such apparatus: in the one on the right the movable cistern is in its lowest position; in the other, on the left, in its highest position. A is the vessel which is to be the movable cistern of mercury; B and *g*, vessels corresponding with the top of the barometer tube, where the vacuum is to be produced. The two vessels A and B are connected with each other by means of a wide india-rubber tube R and a small tube *r*. At Z in the vessel B a third tube S branches off, which is bent, as shown in the figure, and connects B with the vessel *g*. The vessels A can be moved up and down between the two vertical beams of the frame. In the lowest position, as in pump I, the surface of the mercury contained by them must be distant more than 760 millimetres, or 30 inches, from Z. The height of tube S S must also not be less than 760 millimetres. The vessel *g* contains sulphuric acid, which withdraws all moisture contained in the air. Connected with this vessel *g* are the several lamps from which air is to be expelled. They are placed on a horizontal tube with vertical mouth-pieces, and the pump works as follows. By lifting A the mercury contained in it will flow towards B and fill it, and when A has reached the

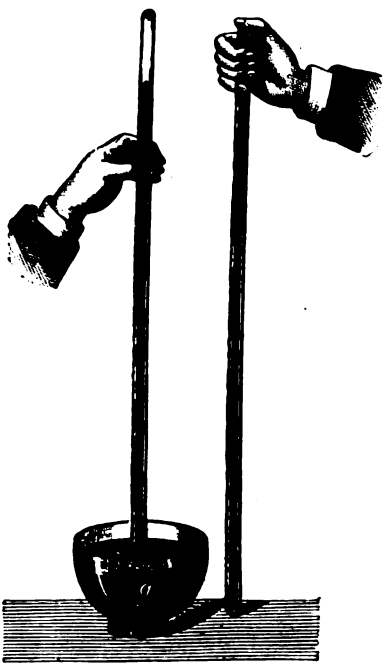


Fig. 452.—Torricelli's Vacuum

position shown in pump II, the mercury of B will flow through the tube *r* back again towards A, driving the air before it. The air is in this way driven out from

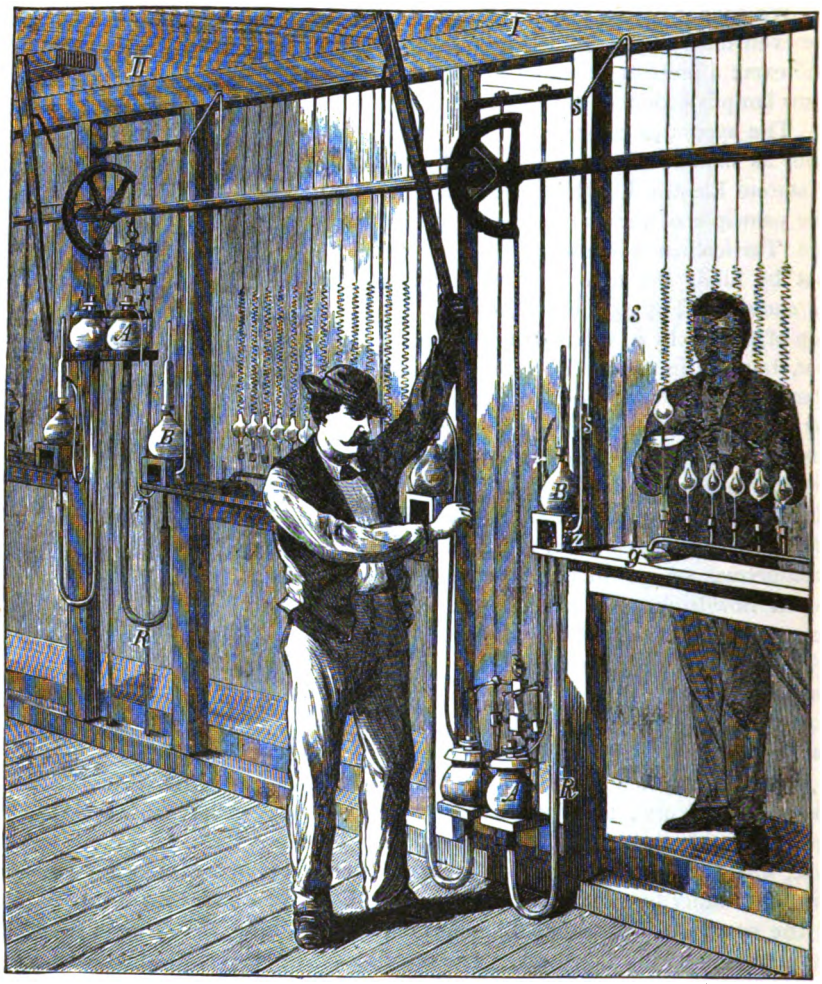


Fig. 453.—Mercury Air-Pumps.

the vessel B through the tube *r*, which terminates in A. Although the air from B may be forced through *r*, no air can be forced back to B, as the tube *r* terminates in A containing mercury, hence *r* acts like the valve above referred to. By lifting and lowering A, a quantity of air is removed, of normal pressure, equal to the volume of R + B. The pressure now on the outside

will not let all the mercury return to A, but will keep the column of the mercury in the tubes R and *r* at a certain height. Continued lifting and lowering of A will drive more air through *r*, until all air is driven out of B. As soon as the mercury has risen beyond Z, two ways are left open to it, viz. B and S; it enters both, and rises in S until the column of mercury balances the pressure of the air in the lamps. When the pressure of air in the lamps is reduced to nothing, on lowering A again the column will fall to the same height as in the barometer column. This is why, as we have stated, the tube S has to be higher than the barometer column of mercury. Care has to be taken that the lifting and lowering of the vessel A shall be done at the right time, and that it shall move with the required velocity. Twelve lamps are exhausted by one pump at a time, all being connected by means of tubes with the pump, and each lamp being suspended from spirals. During exhaustion an electric current is passed through the carbon of the lamp. As soon as a vacuum is obtained the lamps are sealed by means of a blow-pipe flame. The completed lamp is shown in Fig. 450 (7).

The Mode of Fitting Edison's Lamps.—Th. du Moncel has given a minute description of the large establishment at Troy, near Paris, for the manufacture of Edison glow lamps. As we have mentioned already, the carbon filament of the Edison lamp is obtained from bamboo fibres, from bamboo canes of three years' growth. At Troy the bamboo is cut in strips of two sizes, corresponding to the two different sizes of the lamps. The A lamp, of sixteen standard candles, has a carbon the resistance of which is 140 ohms, and the B lamp, of eight standard candles, has a carbon the resistance of which is from 60 to 70 ohms. The glass vessels and glass tubing are obtained from the Bohemian glass works, and are not manufactured at the factory. The fastening of the carbons to the flattened copper wires, which are connected with the platinum wires fused in the glass, is done by women. To make good contact at the junctions, copper is deposited round them by the electric current. The carbon with its glass tube is then placed in the glass vessel, and the glass is fused. Care is taken that the heated glass is allowed to cool gradually, to prevent breakage. For this purpose the lamps have to pass burners of graduated intensity, and when they arrive at the last one the lamps are fit to be removed to the exhaustion rooms. Exhaustion at Troy is done by means of Sprengel's mercurial air-pumps. The pumps are arranged along the wooden wainscoting of the walls of a large room. P (Fig. 454) represents one of them. Above and below P run iron tubes D D and D′ D′, which allow the mercury to pass and re-pass. Each of these tubes terminates in a mercury reservoir. The upper reservoir is connected with the lower by means of a slanting tube and an Archimedean screw, which is set in motion by a motor. By means of this screw the mercury from the lower reservoir is made to reach the upper reservoir. From the upper reservoir the mercury flows through the horizontal iron tube D D into the vertical india-rubber tubes B to the several pumps. The mercury falls down the tube A B, and flows through

the inclined tube at C into the vertical tube T. Here the mercury encounters an air column, which is carried in the form of air bubbles along with the mercury through the tube T B′ (80 centimetres or 30 inches long). The space within the tube which lies above the mouth of the slanting tube is gradually deprived of air. Tube T continues along S and terminates in the reservoir R containing sulphuric acid. The lamp L to be exhausted is fastened to the mouth-piece O of this reservoir.

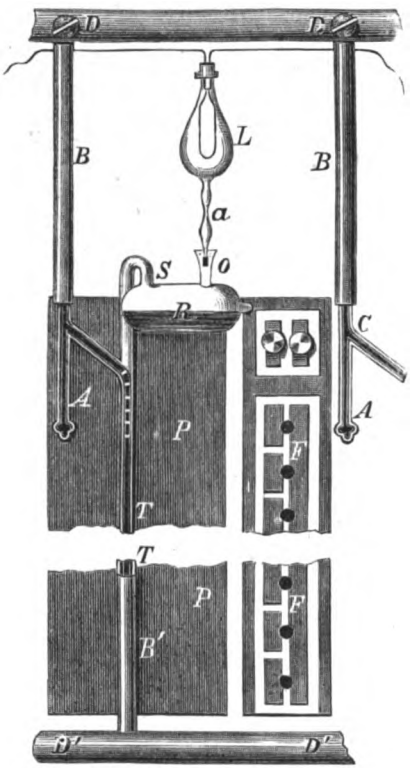


Fig. 454.—The Sprengel Mercurial Air-Pump.

The carbon of the lamp and a rheostat F are inserted into the circuit of an electric current. At the commencement of exhaustion all the resistances F are inserted, and therefore only a weak current will go through the carbon. The resistances are gradually taken out, and the current allowed to pass in its full strength. If now the lamp glows with the required intensity, further flow of mercury is prevented by means of the cock D. The lamp has now to be finished in the way we have already described (page 469).

Comparison of Glow Lamps.—To compare glow lamps with each other we must know the energy required, that is to say, the product found by multiplying the difference of potential in volts by the strength of current in amperes. This, however, does not mean that as long as the product is the same the difference of potential or the strength of current may vary. There are lamps which are designed to use currents of high potential and moderate strength, and lamps designed to use currents of low potential and considerable strength. If with both kinds of lamp the same intensity of light is to be obtained, the lamps which are to be worked with currents of high potential and moderate strength must have their carbons comparatively long, but of small cross section. Those lamps, however, which are to be fed by currents of small potential and great strength must have short carbons of large cross section. The extent to which we can increase the potential depends upon the durability of the carbons. The higher the potential, the longer must the carbon and smaller the cross section become. The glow lamps by Siemens and Halske of ten standard candles, supposed to work with currents of 105 volts, have carbons the length of

which is 110 millimetres and the cross section of which is ·15 square millimetre. It is evident that further diminution of the carbon would increase its frailty.

Again, the limit of current depends not only upon the carbon, but also upon the system of conducting. Lamps to be worked with currents of great strength, but low potential, must be supplied, as we have said, with short and thick carbons, in order to reduce the resistance; and when we bring this large mass of carbon to a glow, we not only lose a portion of the energy, but we also wear out the lamp sooner. Again, the strength of the conducting wire must be such as to prevent the danger of fire, and increase of material means increase of cost. A mean, therefore, has to be sought, and a loss of energy of about 10 per cent. is necessary in practice.

Let us now compare two conducting systems, say Edison's and Swan's, assuming that in both the same percentage of energy is lost. The energy is given by the product of the strength by the potential, or the product of the square of strength of current by the resistance. If the product of the square of current by the resistance is to remain the same for both systems, by using lamps that require currents of different strength the resistance in the system will have to alter with the square of the strength of current. If we increase the current two, three, fourfold, the resistance will have to be diminished four, nine, sixteen times. This may be obtained in the system by taking the cross section of all conductors four, nine, sixteen times larger. We may, therefore, say that the cross section, and also the weight of the system, must increase with the square of the current required to work the lamp. As the Swan lamp requires a current twice as strong as that of the Edison lamp, a system with Swan lamps requires four times the weight of conducting material as is required by an equally large system with Edison lamps. It would, therefore, not be advantageous to employ lamps that require currents of great strength except when the system is very long, as, for instance, when the lights are fed from a central station. The disadvantage of using lamps requiring currents of great strength but low potential may be compensated by using them for short circuits, and joining two or three in series. This arrangement answers well when all the lamps of one group are put out or put on at the same time, as for instance in theatres, railway stations, and large buildings.

Up to the present, in comparing glow lamps, we have assumed the carbons to be maintained at equal temperatures. It is, however, of importance that we should know to what temperature the carbons may be heated with safety. The increase of temperature influences the intensity of the light, both by increasing the number of rays of light, and by increasing the intensity of each ray. More light, therefore, is obtained by expending a certain power, as, for instance, one horse-power, with a higher temperature of the carbon, than with a lower. Siemens mentions that certain carbons at red heat only give an equivalent of ten normal candles, whilst with the same expenditure of power at white heat, 300 normal candles are obtained.

Luminous bodies emit both light-rays and heat-rays, but for our purpose the former only are of use. Hence, the conversion of electricity into the latter is a loss to us; it is, therefore, of importance to know the percentage of light and heat rays which a luminous body emits. A solution of iodine in carbon disulphide has the property of absorbing light-rays and allowing heat-rays to pass. Experiments made by Tyndall with different sources of light gave the following results as the percentage of the whole rays stopped as light-rays by the iodine and disulphide: flame of an oil lamp, 3 per cent.; gas flame, 4 per cent.; platinum spiral white heat, 4·6 per cent.; voltaic arc, 10 to 11 per cent. These figures show, then, that even with the most powerful source of artificial light 90 per cent. are heat-rays. Glow lamps come between the platinum spiral and voltaic arc.

The light-giving power is not only affected by the temperature, but also by the radiating power of the luminous body. That different bodies at the same temperature radiate differently may be shown by a very simple examination. Place a piece of glass and a piece of iron in the same furnace fire; when taken out the former will hardly glow, whilst the iron will probably be white-hot. The temperature of the carbon for glow lamps ought, therefore, to be as high as possible up to a certain limit, which is short of that beyond which the lamp itself would be endangered, for hardly any practical result is obtained by increase of temperature beyond a certain limit.

At present the glow lamp is capable of competing favourably with sources of light such as gas, etc., but would never be able to compete, if even further perfected, with the voltaic arc light.

According to experiments made by Tresca, the effects produced by glow light, light of electric candles, and arc light, respectively, are in the ratio of 1 : 3 : 7.

Finally, we have still to consider the influence which the form of the cross section exercises. If two carbons have the same cross section and the same length, but the cross section of the one is a rectangle, and that of the other a circle, then evidently the surface of the former is greater than that of the latter. On the supposition of there being equal temperatures in the two cases, the amount of light given out by the former carbon would be greater than that of the latter, since the amount of light given out is, under these circumstances, proportional to the surface. If, now, we wish to make the production of light the same for both carbons, the round carbon must be prolonged. Then both carbons will have the same cross section, and, therefore, also the same capacity, and equal powers of lighting. In the case of the round carbon, however, the resistance has increased on account of the increase in the length, and this leads to an increase in the intensity of the current. Since this, however, as we have seen before, is advantageous, the carbon having the round cross section is preferable to that with the rectangular cross section.

In order that a glow lamp may as nearly as possible attain perfection, it should be so constructed (1) that the carbon may remain at as high a temperature

as possible, and that its surface may have such a form that the intensity of the rays proceeding from it may receive the greatest possible advantage; (2) that the methods of producing the vacuum may be as simple and perfect as possible; (3) that the expenses of the conduction may be a minimum.

In the following schedule the results of measurements with respect to glow lamps, received at the Exhibitions at Paris and Munich, have been tabulated:

Lamp.	Nominal Candles.	Light Intensity, Standard Candles.	Resistance (Warm) Ohms.	Difference of Potential in Volts.	Current in Amperes.	Electric Energy in		Light Intensity per H. P.	No. of Lamps per H.P.
						Volt-Amperes.	H. P.		
RESULTS GIVEN BY THE EXHIBITION COMMISSION AT PARIS.									
Edison, A ...	16	15·38	137·4	89·11	0·6510	57·98	0·0788	196·4	12·28
,, C ...	32	31·11	130·03	98·39	0·7585	74·62	0·0941	307·25	9·60
Swan, A ...	16	16·61	32·78	47·30	1·471	69·24	0·0945	177·92	11·12
,, B ...	32	33·21	31·75	54·21	1·758	94·88	0·1059	262·49	8·20
Lane-Fox, A ...	16	16·36	27·40	43·63	1·593	69·53	0·0125	173·58	10·85
,, B ...	32	32·71	26·59	48·22	1·815	87·65	0·1289	276·89	8·65
Maxim, A ...	16	15·96	41·11	56·49	1·380	70·85	0·1191	151·27	9·45
,, B ...	32	31·93	39·60	62·27	1·578	98·41	0·1337	239·41	7·48
RESULTS GIVEN BY THE MUNICH COMMITTEE.									
Edison, B ...	8	11·69	67·68	55·78	0·825	46·02	0·0625	186·90	23·36
,, A ...	16	15·32	139·60	103·05	0·755	77·80	0·1057	144·88	9·05
Maxim ...	28	13·34	47·01	65·07	1·384	90·06	0·1224	108·98	3·89
Swan, A ...	10	10·95	31·91	38·38	1·222	46·90	0·0637	171·78	17·18
,, B ...	40	37·17	87·03	118·02	1·282	151·30	0·2056	180·75	4·58
Siemens ...	16	14·90	104·72	95·74	0·915	87·60	0·1191	125·14	7·82
Müller, A ...	20	18·43	58·62	74·94	1·263	93·51	0·1271	145·01	7·26
,, B ...	50	43·08	59·52	105·22	1·779	187·19	0·2544	169·33	3·39
,, C ...	100	102·35	65·41	155·15	2·367	367·24	0·4991	205·05	2·05
Cruto ...	10	8·47	8·16	22·15	2·715	60·14	0·0817	103·58	10·36

HALF-INCANDESCENT LAMPS.

General Description.—In these lamps the light arises at the point of contact of the electrodes. They are, therefore, also called contact glow lamps, or glow lamps with partial contact. Werdermann has established, by means of numerous experiments, that if the cross section of the + carbon be diminished, and that of the − carbon at the same time be increased, the glow of the latter will continually become weaker, while that of the former will become stronger. On account of the inequality of the cross sections, the resistance of the current received at the point of contact is increased, and, therefore, an increase of heat takes place. If the ratio of the cross section of the + carbon be to that of the − carbon about as 1 to 64, the latter will not be heated at all, while the + carbon will burn with the production of a fine, steady light.

The half-incandescent lamps are quite a recent invention. Varley, according to Fontaine, was the first to make such a lamp. He described it in the

patent of an electrical machine which he took out in 1876. The lamps on this type, however, which were invented by Reynier, Markus, and Werdermann, in 1878, were the first the action of which was regular.

The following is the principle of the glow lamp of Reynier: Suppose a thin strip of carbon which is pressed at the side by an elastic contact, and which is pressed in the direction of its axis against a fixed contact. If a sufficiently strong current flows through this piece of carbon, the point of the carbon against the fixed contact glows to whiteness, and burns up, while the end remains pointed. By means of the constant pressure upon it, the strip of carbon advances as the end consumes. It slides through the elastic contact, and, at the same time, constantly rests on the fixed contact. The heat, generated in consequence of the passage of the current through the strip of carbon, is increased considerably by the simultaneous consumption of the carbon, and the lighting power is consequently assisted by this consumption.

The essential features of Reynier's plan, therefore, consist in taking a very long pencil of carbon for one pole, and a block of carbon for the other, and providing the pencil with a contact at the side. The pencil forms the + pole, and the block the – pole. The defects of this lamp, in its original form, were that the metallic impurities of the carbon pencil settled as ash on the carbon block and spoilt the arc. To avoid this, Reynier substituted a revolving disc of carbon for the block, and let the pencil of carbon touch the disc near the axis on which it turned. The pressure of the carbon pencil on the disc caused the latter to move, and new portions to come in succession into contact with the point. The lamp is shown in Fig. 456; the brass rod, S, sustaining the + carbon K_1 slides in telescope fashion in the tube M. The – carbon is the disc K_1, which is attached to a lever G, having a spur that presses against the tube S, and acts as a brake to retard the motion of S. The pencil K is directed by a copper pulley r on an inclined arm, and the conduction of the current follows from a small carbon block on the same arm, and kept by its own weight in contact with the electrode. The current enters at the clamp P_1, passes through the mass of the lamp to the + pencil, then to the – disc, then into the insulated bearers of the lamp to the clamp P.

The pencils have a diameter of 2 millimetres and a length of ·3 metre, and last two hours. The intensity of the light varies as the number of lamps in the circuit. Thus the intensity with 6 lamps and a Gramme machine making 920 revolutions per minute was 13 Carcel burners. The total intensity was, therefore, 78. A Serrin regulator, under similar conditions, gave an intensity of 320 Carcel burners.

Markus's lamp has a similar construction, but produces the displacement of the point of contact by a rotating cylinder.

The latest model of Reynier's lamp is represented in Fig. 456. Two tubes P_1 and P_2, telescoping one in the other, are fixed to a plate P. The outer tube P_1 is insulated by means of the black ring from the plate P, and connected with the — clamp; the latter (P_3) is connected with the plate P

and the positive clamp. The two tubes are insulated from each other; the barrel *g*, which carries the contact pin *c*, is fastened to the tube P_2. The contact pin consists of graphite, and is pressed by means of the spring *f* against the carbon rod K from *g*. The arm *t* is insulated and carries the negative pole *s*, which consists, like the contact pin *c*, of graphite, enclosed

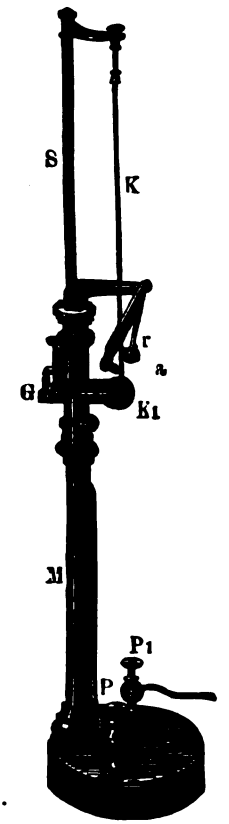


Fig. 455.—Reynier's Lamp.

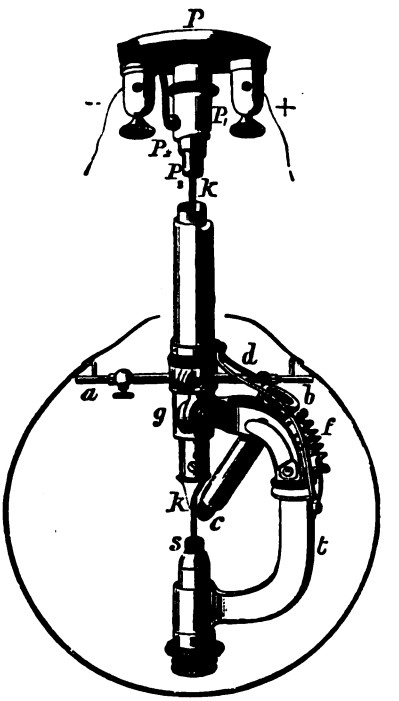


Fig. 456.—Reynier's Improved Lamp.

in a brass tube *s*, and is connected by means of *t* and the fork-shaped wire *d* with the tube P_1. The carbon rod K is pressed against the graphite *s* by means of the cylindrical weight P_3. The arms *a* and *b* support the glass globe. The current enters at the + clamp, flows through P_1, P_2, *c*, and K. Here the glow light is produced, owing to the imperfect contact with *s*. The current then flows through *t*, *d*, P_1 to the − clamp. The diameter of the carbons in this lamp is 2·5 millimetres, the length 1 metre. The lamp lasts six hours. The length of the glowing portion may be varied from 4 to 8 millimetres,

and the light produced is equal to from 5 to 20 Carcel burners. With a Bunsen battery (eight elements having large plates) a light is obtained equal to 12 Carcel burners. When fed by machine currents the lamp gives 30 to 40 Carcel burners per horse-power. Several of these lamps can be inserted in the same circuit.

Werdermann's Lamps.—In the lamps by Werdermann the negative carbon is arranged above the positive (Fig. 457). The positive carbon rod is attached to strings which run over pulleys *r* and are fastened to the cylinder *c*, which serves as a counter-weight. By means of this cylinder *c* the rod is pressed against the carbon disc *s*. A spring *f* is fastened to the horizontal arm, and presses upon *b*, which is movable. If the carbon rod is pressed strongly against the disc, the spring *f* will also press strongly against *b*, and will thus prevent the further pushing up of the carbon rod. If the contact has become loosened through the burning away of the carbon rod, the pressure upon *b* will diminish also, and allow the carbon rod to be forced up. If several lamps are joined in series, when one goes out, *i.e.* when there is no contact between rod and disc, the horizontal arm is lowered so as to put the lamp out of circuit, and insert the others.

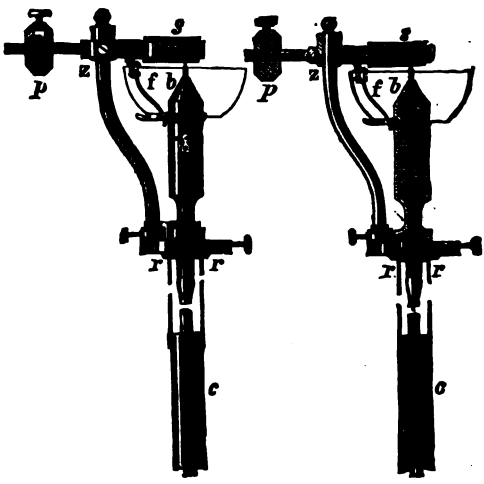


Fig. 457.—Werdermann's Lamp.

Brougham's Lamp has no mechanism, but the air is excluded so that the carbon rod is made to last longer. The glass cylinder *g g* (Fig. 458) is covered by the lid s s; a tube is fastened to the lid, which has some insulating substance inside, and contains an inner tube *r r*, in which the carbon rod *k* is placed. The rod *k* is pressed down by the platinum clamp by means of a little weight. Opposite this clamp is a conical piece of copper c fastened to the lid *s s*. After the carbon rod has been introduced the tube *r r* is closed air-tight, and the whole lamp is placed in a vessel $g_1 g_1$ containing water. The lid *a a* is to prevent evaporation of the water. The current enters at the tube *r r*, flows through the carbon rod to the copper pyramid, and then leaves the lamp by the outer tube. The carbon is at first consumed, as in ordinary lamps, but as soon as the oxygen contained in the vessel *g g* has been used up, that is to say, in about an hour, the carbon burns very slowly—at the rate of about 3 millimetres per hour. When fed by a small Gramme dynamo-electric machine, thirty-six lamps arranged in a circuit are said to have given a light of thirty-five normal candles each.

Ducretet's Contact Lamp.—The contact lamp by Ducretet is more suitable for the laboratory than for practical use. The carbon rod T is placed in a tube nearly filled with mercury (Fig 459), and is pressed by the mercury against the carbon disc H. The upper end of the tube is closed by means of an insulated metallic box, the opening of which can be made to correspond with the carbon

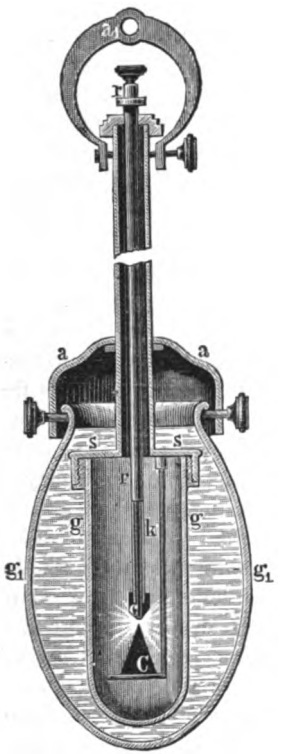


Fig. 458.—Brougham's Lamp.

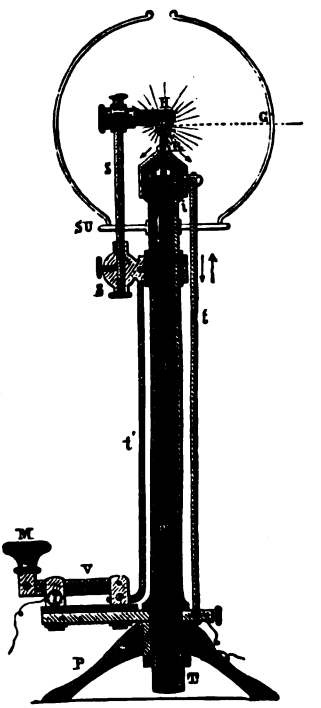


Fig. 459.—Ducretet's Lamp.

rod. The box is connected with a clamp at the foot of the lamp by means of the wire *t*. The other pole-clamp is arranged as a key M V for making and breaking contact. The latter is connected by means of the wire *t'* and S S with the carbon disc. The metallic box at the top of the tube containing the mercury is considerably heated; practice, however, has shown that only a small portion of the heat is communicated to the mercury. The greater portion is conducted away by means of *t* to the foot of the lamp, thus avoiding the production of unpleasant mercury vapours.

Hauck's Lamp.—W. Ph. Hauck substituted glycerine for mercury in the lamp represented in Fig. 460. The carbon K rests with its lower end upon a

brass pin fastened to a float, which floats on the glycerine contained in the cylinder C. The carbon rod is placed in a copper tube fixed to the lid. Over this copper tube there is a soft iron tube E; one end of the coil D which surrounds E is connected with the clamp P', the other end with the soft iron tube E. The latter has at its upper end the iron fork G, in which the iron lever H moves. This lever is bent at right angles, and forms the armature of the electro-magnet E. The same polarity will be produced at the bent end of the lever and the upper end of the electro-magnet, and therefore by this arrangement the attraction between armature and electro-magnet is increased. To the upper end of the lever the roller R' and carbon disc S are fastened. The spring F regulates the position of the lever. As long as no current passes through the lamp, the disc S, aided by the spring F, keeps the lever from the electro-magnet. At the same time the pulley R' is held apart from the pulley R, and the carbon rod is allowed to touch the disc. As soon, however, as a current passes through the lamp, D attracts the armature H, pressing the pulley R' against the carbon rod, whilst S moves back a little at the same time. In this manner the carbon disc is saved from excess of pressure, which might cause it to break. As the break of contact takes place before the carbon disc and carbon rod touch each other, an opportunity is given for the formation of a minute voltaic arc. The current flows from P to the copper tube, through the pulleys, the carbon rod, the carbon disc G, into the iron tube E, through the coil D, and finally leaves the lamp by the clamp P'. The ascent of the carbon rod is delayed until the resistance in the circuit has increased by the burning away of the rod, and the current in D is diminished until the armature H is pulled off the electro-magnet by the spring F. To obtain a still more sensitive regulation the iron tube has several layers of fine wire wound round it, and joined as a shunt, so that when a current passes poles

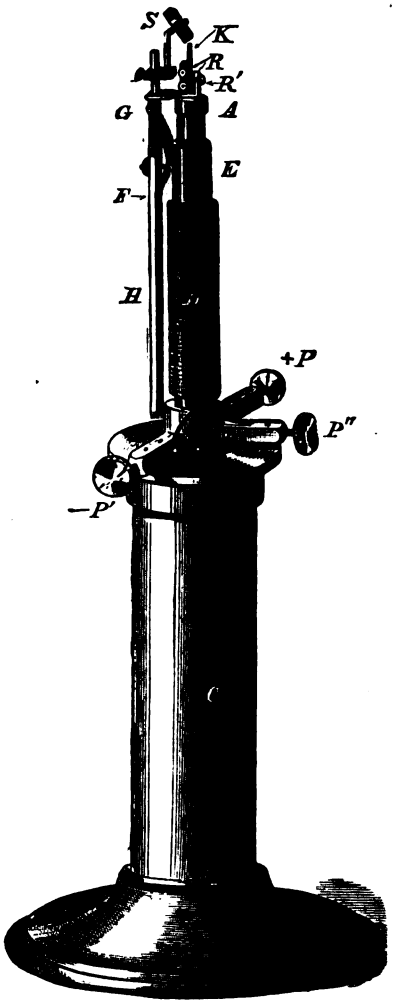


Fig. 460.—Hauck's Lamp.

are produced in the iron tube which are opposite to the poles produced by the direct wires. When the resistance increases in the main circuit to a certain limit, the shunt circuit weakens the main current, the magnet loses its power, and the armature is taken off by the spring. When the carbon rod has been entirely consumed, the bent end of the lever H touches a platinum contact, which is connected with the clamp P″, causing the insertion of another lamp, or a corresponding resistance. This is brought about in the following manner: As long as there is any of the carbon rod in the lamp, the lower end of the lever H cannot touch the platinum contact; when, however, the carbon is consumed, the brass pin of the float will come between the pulleys, and being much thinner than the carbon rod, will allow the pulleys to come closer together, and will also allow the lever to reach the platinum contact.

Jöel's Lamp.—The lamp constructed by Jöel (Fig. 461) consists of a copper jacket divided into portions I and II, insulated from each other. The light is produced by the heating to incandescence of the end of a thin carbon rod or pencil, which forms one electrode, and which is continuously fed through special and simple contact jaws J against a fixed cylinder of iron E forming the other electrode. The length of carbon between the jaws and the iron cylinder is about $\frac{3}{4}$ inch, and from this the light emanates; chiefly, however, at that part near the fixed cylinder, where it becomes pointed by the action of the current, and consequently more intensely heated. In addition to the light produced by the incandescence of the carbon, there is also the glow or flame from the sides of the burning carbon to the iron electrode similar to the flame of an arc light, the light thus taking an intermediate position between the purely incandescent system and the arc lamp of Pilsen. A peculiar feature in the light is that the incandescent point of carbon becomes slightly curled in shape, somewhat like a mushroom, where it wastes away, and is replaced by the gradual forward

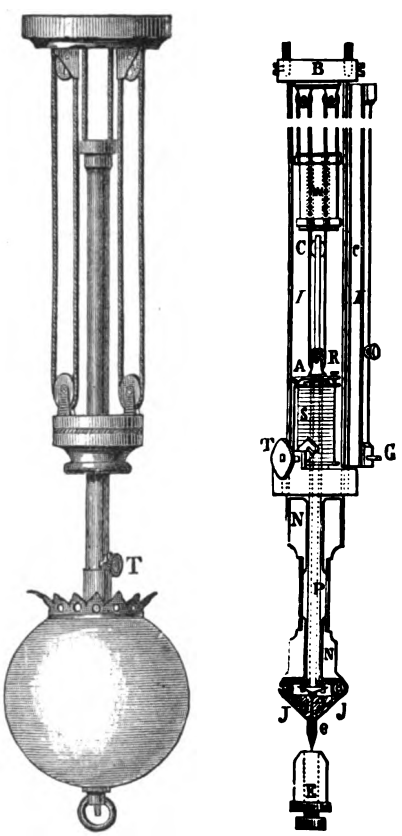


Fig. 461.—Jöel's Lamp.

motion of the pencil. The fixed electrode remains intact, and lasts for any required time. The carbon consumes from 2½ to 3 inches per hour for lights of 100-candle power and upwards. The pencils are 5 millimetres diameter, and in lengths of ½, ¾, and 1 metre.

The improvements in the lamp consist chiefly in the simplification of the mechanism in connection with the contact jaws, by which means the lateral pressure is always proportional to the upward pressure; also in the details for making the lamps in the same circuit independent of each other, and increasing the general adaptability for the purposes of domestic and interior lighting. Referring to the sectional view of the lamp (Fig. 461), E is the fixed iron electrode with the point of the carbon pencil pressing upon it. The contact jaws are shown at J. The weight W, which actuates the lamp, is suspended by the continuous cords which pass up and over the rollers R, attached to a collar C, and down again through a roller R, attached to the under-side of the carbon pencil holder. The collar C and rollers R are attached to a light tube, which passes up through a nipple N, and terminates in a flange above the horizontal arms of the cranked jaws J, thus producing the lateral pressure on the carbon. The collar C is of iron, and forms an armature of an electro-magnet S, wound with fine wire, and so arranged that if an arc should form between the carbon and the iron electrode E, the electro-magnet S would come into action, lift the weight, and free the jaws J from lateral pressure. The carbon holder is also arranged so that when the carbon pencil is nearly consumed the lamp is automatically put out.

The current enters part I of the lamp, flows through N N and the jaws J J into the positive carbon *e*; from there to the negative pole and part II, and then back again to the source of electricity. During consumption of the carbon the resistance is increased in the just now mentioned circuit, and a larger and larger portion will go through the branch circuit of electro-magnet S, which finally attracts its armature, and lowers tube P; with it pressure against the upper levers J J ceases, the lower levers open and allow the carbon rod to slide down until E again is reached. This causes a diminution of resistance in the lamp circuit, and consequently a diminution of circuit in the electro-magnet, which lets go its armature, and causes the jaws to press against the carbon rod. When the carbon rod has been consumed, the carbon-holder comes partly out of the tube, causing a short circuit, which takes the lamp out of circuit; if a new carbon rod is to be put in without disturbing the other lamps burning in the same circuit, the lamp itself is short-circuited by means of the pin G, part II, and hook T, part I. According to the length of carbon rod, the lamp lasts from seven to fourteen hours. Professor Adams obtained a light of 715 candles per horse-power with a Jöel lamp.

REGULATED ARC LAMPS.

Foucault and Duboscq's Apparatus, although not adapted for ordinary lighting, is often employed in laboratories and lectures (Fig. 462). The box B B contains two pieces of clockwork worked by the springs L′ and

L. The clockwork L terminates in the spur-wheel O, and clockwork L′ in the spur-wheel O′; between these is the catch-pin T *t*, which will stop or release either. Which of the two clocks is stopped depends on whether the force of attraction of the solenoid or the force of springs is the greater. By means of the wheel S one or the other clockwork is stopped. One clock causes the carbon-holders to approach each other, the other causes them to recede. The wheels are so geared that one of the carbon-holders is made to move twice as fast as the other. The current enters at C, flows into the solenoid, through D, and leaves the lamp through the upper carbon-holder H. When the carbons are at the right distance from each other the forces of solenoid and spring are balanced, and T *t* stands midway between the spur wheels stopping both clocks. If the distance between the carbons becomes too great, on account of the greater resistance the current diminishes as well as the force of attraction of the solenoid. The spring will draw T *t* towards the right, liberating the clockwork connected with O, and causing the carbons to move towards each other. As soon as the right length of the arc is obtained, the solenoid will also have regained its original force of attraction, and will draw the armature again towards itself, causing T *t* again to stop both clocks. When the arc is too small, the force of the solenoid increases, and draws T *t* towards the left, liberating the clockwork connected with the spur-wheel O′, which causes a separation of the carbons until the normal length in the arc is obtained. The complicated mechanism, and necessity for rewinding the clock, prevent this lamp being largely used for practical purposes. Moreover, only one Foucault lamp can be inserted in a circuit.

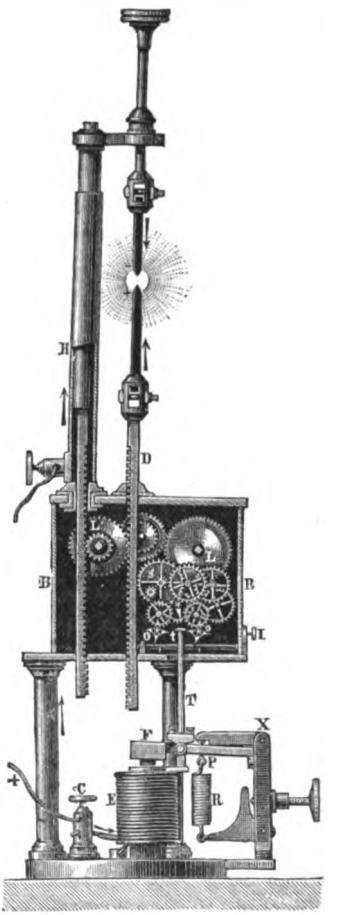


Fig. 462.—Duboscq's Lamp.

Mersanne's Regulator.—In Mersanne's lamp (Figs. 463 and 464) clockwork is used, with two electro-magnets, one inserted in the main circuit, the other in a shunt. The current passes first through the electro-magnet C C, then through the box *i*, the carbons *c c′*, the box *i′*, and then to *g*, where it leaves the lamp. The electro-magnet attracts its armature Q *q*, causing the box *i* to move to the left. The carbons then move away from each other, and the arc is produced. When the distance between the carbons becomes too great, a greater

portion of the current goes through the branch circuit in which the electro-magnet B is inserted. The latter attracts its armature *n*, causing *u* to move back, and releasing the wheel and the clockwork. The carbons will approach until the arc has again its normal length, when the current in the branch circuit will become weaker, the magnet will let go its armature *n*, and the clockwork will again be stopped. The lamp by Mersanne burns for a considerable time without needing renewal of carbons or any other attention. The clockwork once wound up goes for thirty-six hours. The regulation, however, is not sufficiently exact to make the lamp available for lighting buildings, although it might be used advantageously for lighting streets. Fig. 464 represents the same lamp with a kind

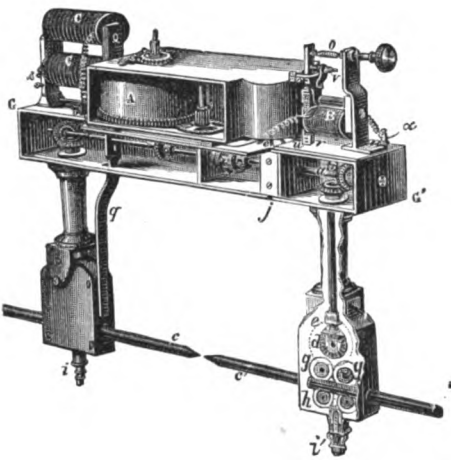


Fig. 463.—Mersanne's Regulator.

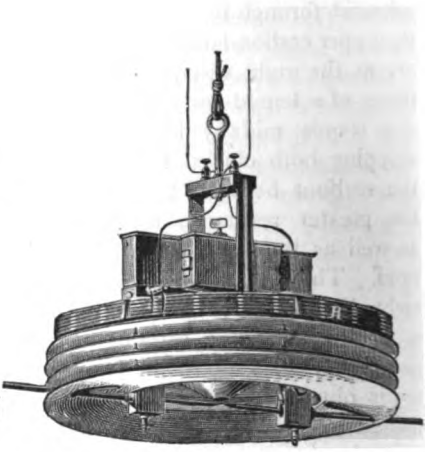


Fig. 464.—Mersanne's Reflector Lamp.

of reflector. Lamps regulated by clockwork have been constructed by others, but in the simpler forms of this class of lamps the force of gravity effects the regulation, checked by a solenoid or electro-magnet.

Gaiffe's Regulator.—Gaiffe obtained this result by a conical solenoid, formed by increasing the number of the turns of wire at every section from one end to the other successively. H represents the upper carbon-holder (Fig. 465), which can be arranged immediately above H′ by means of the joint V. H is fastened upon the bar I, which moves up and down in the tube J, and has a toothed rack at its lower portion. H′ rests upon a rod K of soft iron also having teeth and reaching into the solenoid L. The lid Q of the solenoid has an opening for K and carries the toothed wheels M and M′. These are insulated from each other by means of an ivory plate, and move upon the axis W. Their diameters are in the proportion of 1 to 2, that is, they are proportional to the rates of consumption of the carbons. The teeth of the larger wheel M gear with the teeth of rod I, the smaller wheel M′ gears with the rod K. The spring O is connected

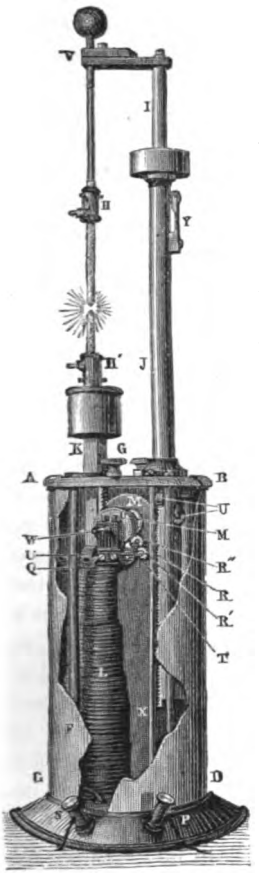


Fig. 465.—Gaiffe's Regulator.

with the two wheels, and tends to turn the wheels so as to move the carbons towards each other. The toothed wheels R R′ R″ can be brought to act with M and M′, and serve to lower and to raise the carbons, without disturbing the action of the lamp, and so as to place the arc at any required height. To add to the steadiness of the carbon-holders the pulleys U are fastened at several places, and a contact roller is fixed to the tube J opposite an opening in this tube, through which it is pressed by a spring Y against the rod I conducting the current. The regulating mechanism is covered by a case A B C D, at the foot of which the pole-clamps P and N are fastened. The regulation of the arc is brought about by the spring O and solenoid L; the former moves the carbons towards each other, the latter by attracting the iron rod K tends to separate them. The current enters the lamp at P, flows through X, J, Y, I, H, to the carbons; then from the rod K to the solenoid L and back again to N. Before the current enters the spring O has brought the two carbons to touch each other; as soon as the current circulates through the solenoid the rod K is pushed down and the two carbons separate and form the arc. The consumption of the carbon causes increase of the resistance in the circuit, and diminishes the force of attraction of the solenoid, allowing the force of the spring to prevail, and causing the two carbons to move again towards each other. The lamp is constructed for a single light, and is well adapted for battery currents. Twenty large-plate Bunsen or sixty small-plate Bunsen elements might be used.

Jaspar's Regulator.—In the lamp constructed by Jaspar the variations in the force of attraction of the solenoid are not avoided, but they are compensated by a corresponding counter-weight. The upper positive carbon (Fig. 466) is fastened to A, and can be adjusted to stand directly above the lower carbon. A is perfectly insulated from the other portions of the lamp, and is connected with the positive pole

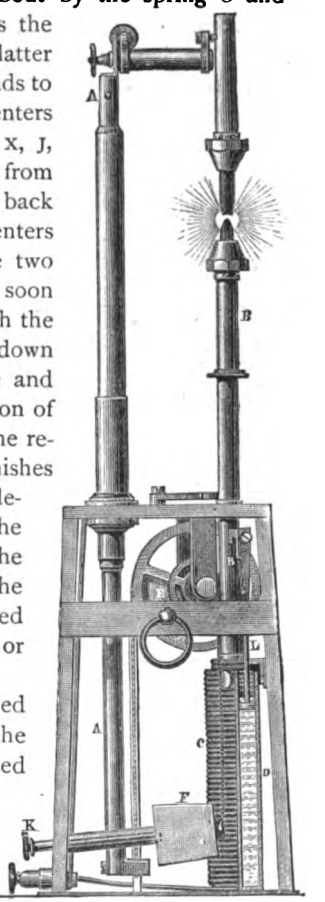


Fig. 466.—Jaspar's Regulator.

of the source of electricity. At the lower end of A a string is fastened which is carried over a wheel, upon the axis of which there is another wheel of half the diameter of the former. The string which passes round the circumference of the second wheel leads to the carbon-holder B. By this arrangement the negative carbon will travel half as fast as the positive. F balances A, and the screw K adjusts the weight F along the lever according to the strength of current. The negative carbon-holder B is made of iron, and reaches into the solenoid *e*; as long as there is no current passing the weight of A prevails and causes A to descend. By means of the strings, B will then be made to ascend, causing the carbons to touch each other. When the lamp is inserted into a circuit, B will be drawn into the solenoid, A will rise, the carbons will be separated, and the lamp will begin to burn. L, which is fastened to B, has at its lower end a piston which moves in the cylinder D containing mercury. There is but a small space between the piston and the sides of the cylinder, so that the mercury secures to the rod L, and consequently the carbon-holder B, a uniform and slow motion. As the carbon is consumed the length of the arc increases, the current diminishes and the solenoid loses force. The weight of A will then prevail, and will cause the upper carbon to descend and the lower carbon to go up, hence the carbons are moved towards each other at the rate at which they are consumed. The force of attraction of a solenoid alters with the position of the iron rod. When the lamp begins to burn with new carbons the carbon-holder B will have its lowest position; and when the carbons are nearly consumed, as shown in Fig. 466, B will have arrived at its highest position. In order to prevent the arc from increasing with the rising of B, the weight E is fastened on the left hand to the large wheel in the drawing, indicating the condition in which the carbons are nearly burnt out. When B has its lowest position the wheel stands so that the weight E is to the right from the axis; the force of attraction of the solenoid is strongest when B is at it highest, but so also is the counter-force of weight E. When the force of attraction of the solenoid is weakest it is aided by the weight E. In this manner Jaspar maintains uniform motion of the carbon-holders in spite of an iron rod of uniform cross section. Jaspar's regulator is constructed for single light and continuous currents, is very sensitive, and produces a steady light. During the Exhibition at Paris a large room was lighted by three lamps; each was placed in a cylinder open at the top, having a reflector, as shown in Fig. 467. This

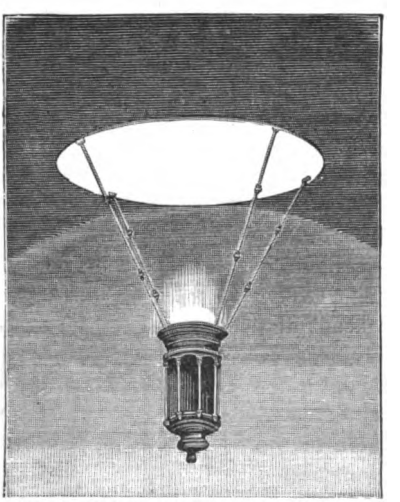


Fig. 467.—Jaspar's Lamp and Reflector.

kind of lighting has the advantage of great divergence, producing a uniform and agreeable light, and hiding the disagreeable arc.

Piette and Krizik's Regulator.—As regards simplicity of construction, the lamp by Piette and Krizik is considered to be among the best for practical purposes. It is more generally known in England as the Pilsen lamp. The iron core is shaped as shown in Fig. 468; here the cross section of the iron increases or diminishes proportionately to the increase or decrease in the force of the solenoid. In all three positions *a*, *b*, *c*, the iron core

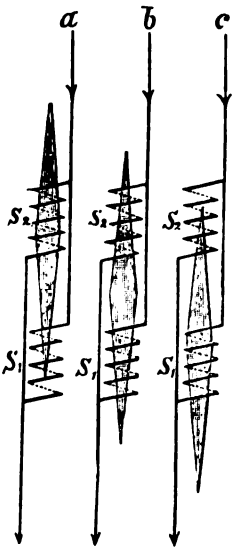


Fig. 468.—Principle of Piette and Krizik's Regulator.

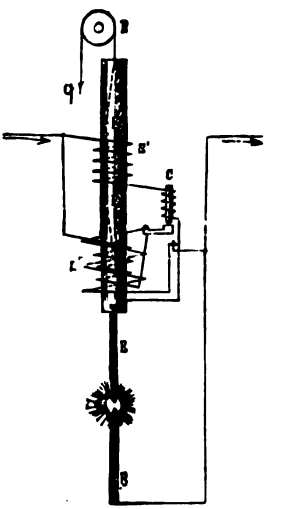


Fig. 469.—Piette and Krizik's Lamp.

will be at rest, assuming that s_1 and s_2 have the same electrical values. If unequal currents pass through the coils, the iron core will be attracted by the coil having the strongest current. Different strengths of current in the two coils are obtained by having one coil of thick wire inserted in the main circuit, the other coil of fine wire in shunt. The direction in which the iron core moves will therefore be determined by the difference of the effects of the two coils. The regulator by Piette and Krizik, therefore, is a so-called differential lamp, the special recommendation of which is that it can be used for divided light. Fig. 469 is a diagram to explain the action of a lamp constructed on this principle. The double conical iron core F F is placed in a brass tube which bears the carbon at its lower end E. The whole is fastened to a string which runs over a pulley R counter-balanced by the weight *q*. The solenoid s' is inserted into the main circuit; the solenoid s'' forms a shunt circuit of high

resistance. At C is an automatic contact-breaker which shunts the current when the lamp goes out. The current enters at s', goes through C to the upper positive carbon, then to the negative carbon and back to the source of electricity. When the carbons are near together, that is, when the resistance in the main circuit is but small, s' becomes very powerful and draws the two carbons from each other; if the resistance is increased during the consumption of the carbons, a stronger current of high resistance will pass through s'', causing the carbons to approach each other.

Fig. 470 shows a horizontal model of this lamp, which was exhibited at the International Paris Electrical Exhibition.

Recently these lamps have been modified (Figs. 471, 472). The coils are arranged side by side, and the double conical core is divided into two portions. Fig. 471 shows a standing lamp, and Fig. 472 shows the same lamp in section,

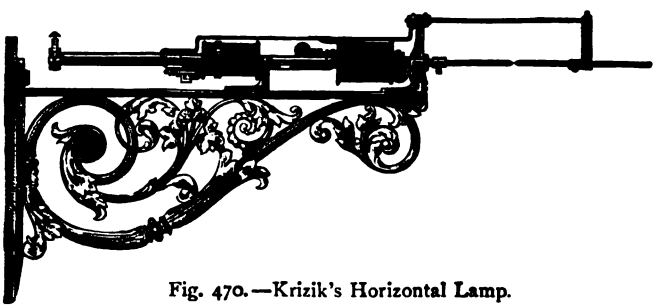


Fig. 470.—Krizik's Horizontal Lamp.

but reversed for the hanging mode of support. E_1 and E_2 are the divided iron cores, H the principal coil with a few turns of thick wire, N the branch coil with a few turns of thick wire and many turns of thin wire; C is an electro-magnet also with double coils, *n* a resistance coil of German silver, *e* a resistance coil of iron wire; g_1 g_2 are the insulated rails along which the core E_2 slides up and down; K_1 and K_2 are the carbons. In order to make the somewhat complicated current conduction better understood we shall consider the different periods: (1) The two carbons do not touch each other when the lamp is to be lighted. The current enters the lamp at + P, flows through *a*, through the thick turns of N, through *b*, *c*, and the platinum contact *d* to *f*, through the resistance wire *n*, where it leaves the lamp at − P. The iron core E_1 will now be drawn down by the spiral *a b*; the carbon K_1 will be lowered to touch K_2. (2) The current upon entering the lamp at + P has two ways open, the way just now described or the following: through the two carbons K_1 K_2, G_1, *i*, *k* to *m*, then through the few thick turns of the electro-magnet C O, through the thick turns of H and through L to − P. The greater part of the current will take the latter course because it offers the less resistance. H therefore draws E_2 down, causing the carbons to separate and producing the arc. The contact magnet C has now become magnetised and attracts its armature, breaking contact at *d*. (3) The current described under (1)

has become a weak branch current, and takes the following direction. From + P through the mass of the lamp to *a*, through the thick and thin turns of coil N and through the thin wires of electro-magnet C, uniting at *m* with the main current, and thence having the same direction along with it as described under (2). (4) The arc increases proportionally to the consumption of the carbons,

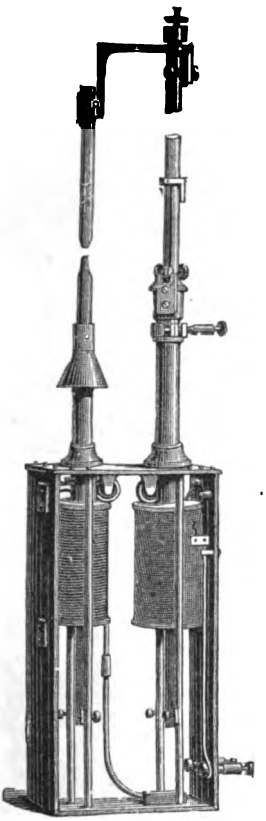


Fig. 471.—Pilsen Lamp.

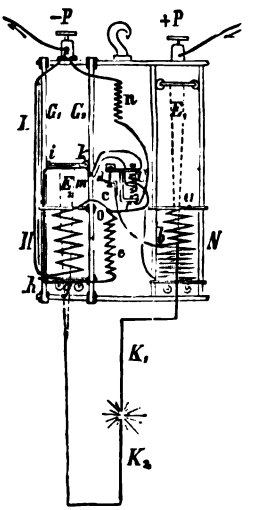


Fig. 472.—Section of Pilsen Lamp.

and thus increases the resistance in the main circuit (2). The branch current (3) increases and becomes sufficiently strong to again attract the iron core E_1 through the coil N, drawing the carbons together, producing the same conditions as were described under (3). (5) We have now only to consider the conduction of current when the carbons are consumed. One of the sliding wheels of E_2 will come in contact with an insulated substance, causing the current to take the following course through the mass of the lamp, K_1 K_2 *g*, *e*, *o*, H, L, to − P. The branch current flows from *a* through the thick wires *a b* of coil N, C, *d*, *f*, *n*, to the negative clamp.

Schuckert, who has undertaken the construction of Krizik's (Pilsen) lamps for Germany, furnishes lamps of 6 to 8 or 8 to 10 hours' duration. The regulating mechanism, as a rule, is surrounded by a cylinder, and the light is protected by a glass globe (Fig. 473). Fig. 474 represents an ornamented lamp as used during the Exhibition at Vienna, by Piette and Krizik. To prevent the casting of shadows by the metallic framework the glass is strongly arched, causing the

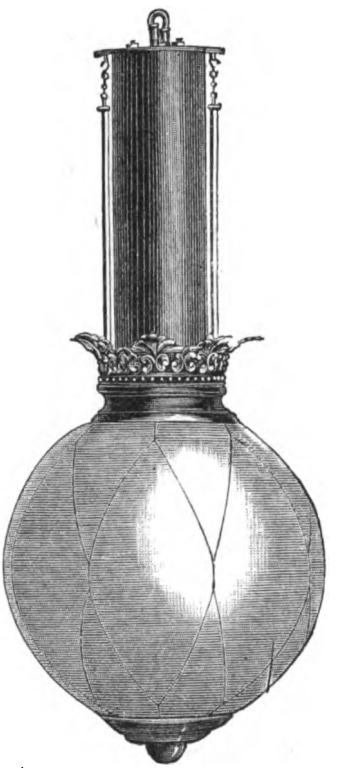


Fig. 473.—Pilsen Globe.

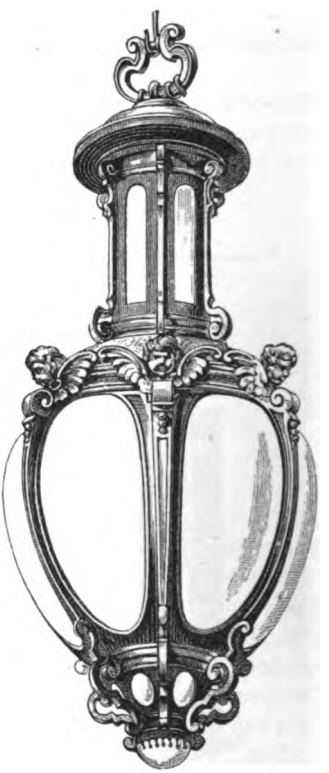


Fig. 474.—Ornamented Globe.

luminous surfaces to over-reach the non-transparent ribs, so that the rays of light by crossing prevent the casting of shadows.

Siemens and Halske's Differential Lamp.—The differential lamp of Siemens and Halske, devised by Hefner von Alteneck, is the first lamp of this kind which is used to any extent for practical purposes; the regulation of the carbons in this lamp is effected by the force of gravity. S S_1 is a rod of soft iron fastened to a lever movable about O, T is a shunt circuit of high resistance, R a solenoid of small resistance inserted into the main circuit (Fig. 475). The coils

of the two solenoids are so arranged as to attract the iron rod in opposite directions, therefore the difference of their forces only causes it to move. Let us assume that the carbons *h* and *g* do not touch, but are some distance from each other. The current then flows from L through the coil T of high resistance to the lower carbon *h*, back over L_1 to the source of electricity; the iron core S S_1 becomes magnetised and is drawn into T, and the end of the lever c_1 is brought into its lowest position; at that moment the carbon-holder *a* detaches itself from the lever $c\,c_1$, sliding gradually downwards until the two carbons touch. The current will now flow from L through R *g h* and L_1; coil R now affects the rod S S_1, drawing it downwards, causing the arc. At the moment the ascent commences, connection between *a* and c_1 is again established. We have now in the circuit, besides the resistance R, the resistance of the arc, which increases with the length of the arc; causing the current to become stronger at T and weaker again at R, until at a certain resistance of the arc the attracting forces of T and R are in equilibrium. The carbon rods are slowly consumed, but the arc is re-formed. The iron rod S S_1 is gradually lifted to a higher position, c_1 sinks to its lowest position, when a loosening of the coupling again takes place, and the whole process is repeated. If the current outside the lamp circuit is altered no change will be experienced by the lamp, because the currents in the two coils vary proportionately. In the lamp itself the carbon-holder *a* z (Fig. 476) is not directly fastened to the lever $c\,c_1$ which turns about *d*. The toothed rod z is only capable of sliding downwards very slowly along with A, thus setting the wheel *r* and the escapement E in motion, and causing the pendulum *p* with its upward arm *m* to oscillate. All these parts are about A and are moved up and down along with it. When the piece A is raised the arm *m* is arrested by a notch in the lever *y*, which stops E and couples A with z. When A reaches its lowest position the lever *y*

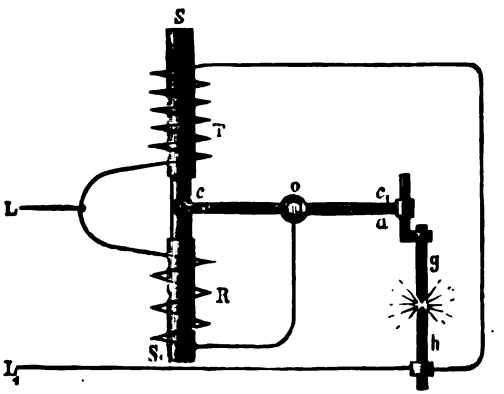


Fig. 475.—Principle of the Siemens Lamp.

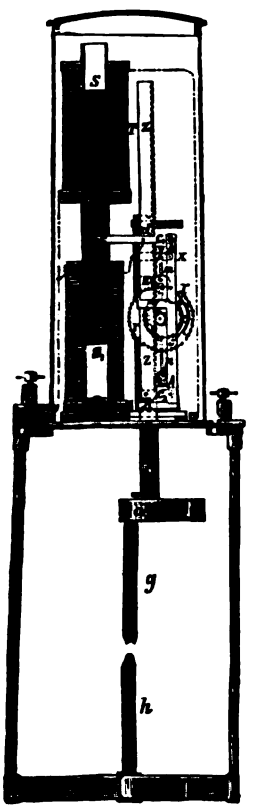


Fig. 476.—The Differential Lamp of Siemens and Halske.

is loosened by a pin, and both E and z are freed from A, and the carbons are pushed together as described. A series of lamps may be inserted in one or several circuits of the machine. When the carbon has been consumed the lamp goes out, and the current goes through the coil of great resistance; to prevent this waste of current Siemens has a contact arrangement which causes a short circuit. The length of each carbon is 40 centimetres; a lamp burns during eight hours.

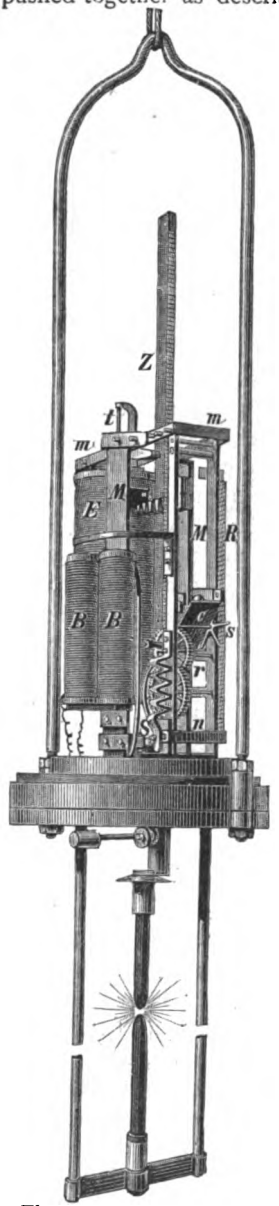


Fig. 477.—Zipernowsky's Lamp.

Zipernowsky's Lamp.—In the lamp devised by Zipernowsky (of the firm of Ganz et Cie.) the adjustment of the carbons is done by the force of gravity, but the motion is regulated by the alternate forces of solenoids. The parallelogram *m n* (Fig. 477) is fastened to one side of the lever *m m*, which moves about a horizontal axis resting upon the beams M M. At the opposite side of the lever the iron core for the solenoid E is fastened. The toothed rod z depresses the upper carbon-holder when the clockwork *r* is not stopped by means of *c*. The solenoid E possesses considerable resistance, and is inserted in a branch circuit to the main circuit. The spring R together with the attraction of E tend to lower the upper carbon, but the weight of the iron core opposes this tendency. The frame *m n* is raised along with the clockwork, the catch falls against the spur wheel *s* and prevents the rod z from moving by stopping the clockwork. If now a current be passed through the lamp it can only flow through the solenoid E, which attracts its core, causing the frame *m m* to move down, which sets the clockwork free, so that the rod z moves down with the upper carbon until the two carbons touch each other; C regulates the motion of z. The whole current will now pass through the carbons, and weaken the solenoid. The frame *m m* rises again, taking the upper carbon with it; z will now be again stopped as described above; the carbons separate and the arc is formed. The resistance of the voltaic arc increases proportionally to the consumption of the carbons, so that the strength of current also increases until its force of attraction is sufficient to lower the frame *m n* by lifting its iron core, and so set free the clockwork, then z will be able to sink down again until the normal length in the arc is

again obtained. In order to cause the iron core to move uniformly, a piston is fastened to the rod *t*, moving in a copper tube placed inside the solenoid E. When the carbons are consumed a branch current passes through the electro-magnet B B, which attracts its armature, and lowers the frame *m n*. The spring S then comes in contact with the ground plate of the lamp, and makes a short circuit.

Schwerd and Scharnweber's Regulator.—Fig. 478 represents a lamp by Schwerd and Scharnweber. E is the iron core, *t* carries the lower carbon, *z z* the upper carbon; *u* serves as fly-wheel to the clockwork; a piston *b* moving in the cylinder *g*, containing glycerine, prevents a sudden or too quick motion of E.

The Brush Lamps.—In the following series of lamps the clockwork is replaced by a brake ring. Fig. 479 represents such a lamp by Brush. The solenoid A consists of a few turns of thick wire, its core consists of a wrought-iron tube C, the weight of which is partly counter-balanced by spiral springs *c*, adjustable by the screws *d*. The holder B of the upper carbon moves freely in the tube C. The lower carbon-holder can be adjusted by means of the screw G. The iron cylinder supports a hook, which catches underneath the ring D, so as to lift it as the cylinder rises. When no current passes through the solenoid the ring D rests on the ground plate, and the upper carbon is permitted to slide down until it touches the lower carbon. When a current passes through it the solenoid attracts C, and raises the ring D by means of its hook. The edges of the ring in rising catch the carbon-holder B, forcing it to move upwards, and producing the arc. When, through increase of the resistance by the consumption of the carbons, the current becomes weaker, C will slowly sink down, causing the ring again to rest horizontally on the ground plate of the frame, and again allowing B to slide down.

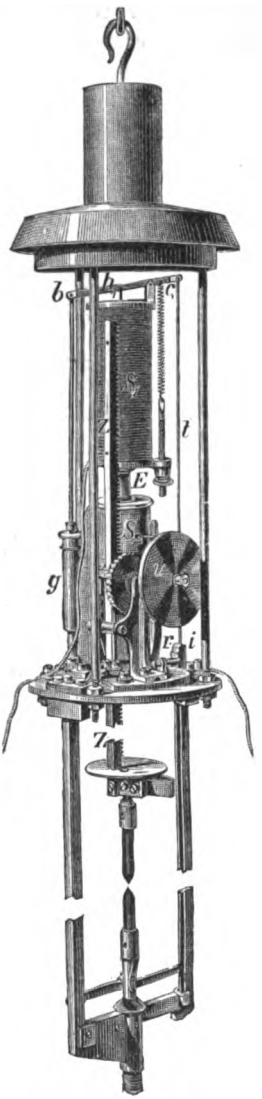


Fig. 478.—Schwerd and Scharnweber's Lamp.

The lamps for divided light have the same regulation mechanism, only the solenoid A has double turns, the inner coils of which consist of thick wire connected with the main circuit, the outer of fine wire connected to a branch circuit. The directions of current in the inner and the outer coil are opposite to one another. The action of the solenoid will be the result of the difference of the magnetic moments of both currents. When the two carbons touch at the beginning,

a strong current will flow through the coil of thick wire, a weak one through the thin wire; the iron core will be attracted with a force equal to the difference of the two magnetic moments, thus striking the arc by the raising of the upper carbon. The current will now decrease in the thick coil in proportion with the consumption of carbons, but will increase in the coil of fine wire. The difference of the magnetic moments of both coils becomes less and less, allowing the core to sink down, and the ring becomes more and more horizontal, allowing

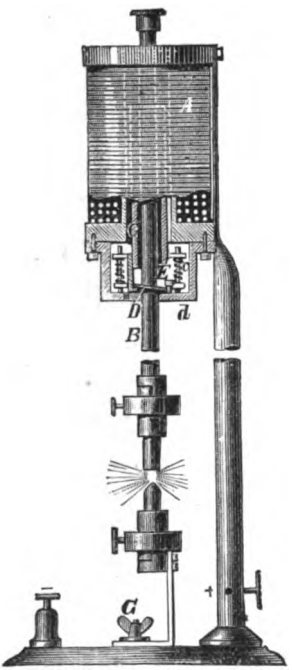


Fig. 479.—The Brush Lamp.

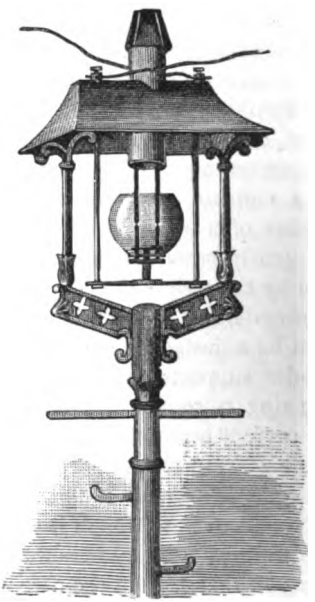


Fig. 480.—Street Lamp by Brush.

the upper carbon-holder to fall. To prevent the carbon-holder going down too quickly it has the form of a tube and contains glycerine, in which moves a perforated piston. The descent of the tube is regulated by the velocity with which the glycerine flows through the piston, and the motion of the carbon-holder is therefore checked. The lamp has a second branch circuit, which serves the purpose, should a lamp happen to go out, of taking it out of the circuit without interfering with the other lamps. An electro-magnet having thick and fine wires coiled round it is used. If the current is interrupted through some cause in the main circuit, a powerful current flows through the thin wire of the electro-magnet, causing it to attract the armature, so as to bring the thick wire coil into the circuit. The current then flows through the armature and the

few turns of thick wire to the next lamp. With a current of 10 amperes the lamps burn eight hours.

Brush constructed lamps which burn longer, having two or more carbon couples. A lamp with two carbon couples, fitted as a street lamp, is shown in Fig. 480.

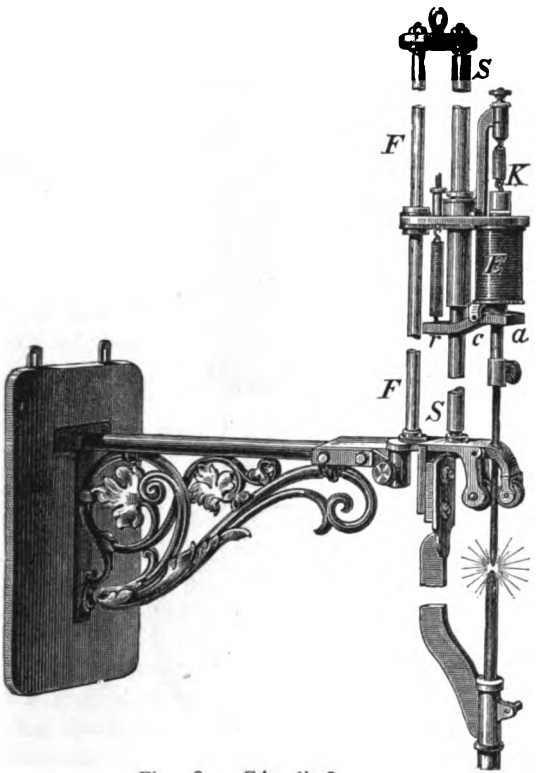


Fig. 481.—Gérard's Lamp.

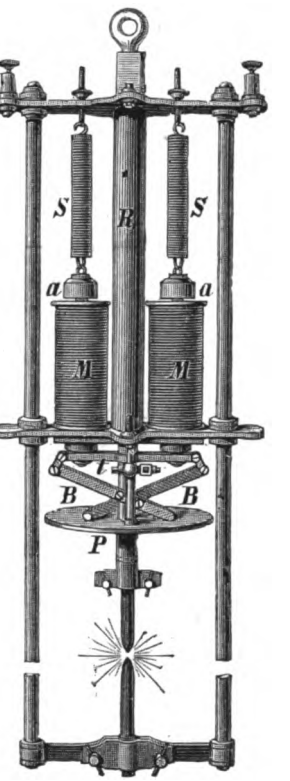


Fig. 482.—Gérard's Lamp.

Schulze's Regulator.—Schulze uses for his lamp, instead of the single brake ring, a frame in which two pulleys can turn, when they are not pressed against the passing carbon in consequence of the slanting position of the frame. The position of the frame is determined by a differential solenoid which influences an iron tube serving as core, as in the Brush lamp.

Gérard's Lamp.—Fig. 481 represents one of Gérard's lamps (lampe à glissière). The spiral spring fastened at *r* opposes the force of the electro-magnet E. When the magnet is currentless, the spring *r* draws the lever to the left, and thus arrests S; when a sufficiently strong current, however, flows through E, *a* is attracted, and therefore sets free S, electro-magnet, carbon-holder, lever and spiral. F F is a guide-rod.

The lamp shown in Fig. 482 is intended for alternating currents. S S are spiral springs, M M hollow magnets, B B the brake arrangement. The form of a differential lamp has been given by Gérard to this lamp. The armatures *a a* are placed between magnets of which the upper couple is inserted in the main circuit, and the lower couple in a branch circuit.

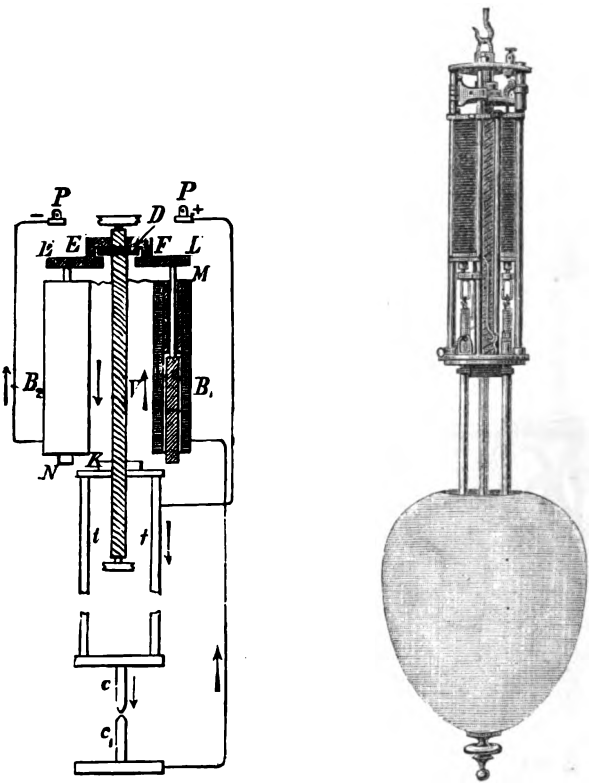


Fig. 483.—Cance's Lamp.

Cance's Lamp.—The brake arrangement in the lamps by Cance (Fig. 483) consists of a female screw E F in which V moves. The current flows through the lamp in the direction indicated by the arrows. The electro-magnets B_1 B_2 attract the cores N N which press against the plate L L. The plate is raised, and pushes against E F.

Weston-Möhring's Lamp.—This lamp is represented in Fig. 484. The armature A of the electro-magnet E E_1 is fastened to the springs F F, and the lever H, which has a hole to let the upper carbon-holder K pass through. The spiral spring S, which can be regulated by means of the screw R, opposes the force of attraction of the electro-magnet E E_1. As long as there is no

current passing through the lamp the lever H is in its lowest position, and allows the carbon-holder K to slide down until it reaches the lower carbon K_1; a current then flows through the coils of the electro. By the attraction of its armature the lever H is drawn upwards, and as the opening of the lever will no longer have a horizontal, but a slanting position, the edges of it will catch the carbon-holder and force it to move upwards with the lever. During the consumption of the carbons the attracting force of the electro diminishes, the armature A sinks, the lever H moving with it, and allowing the carbon-holder to slide down again. To render the motion of the armature uniform, a piston moving in a cylinder containing glycerine is fastened by means of the rod *c* to it. The electro-magnet E has three coils on each of its arms: that which is nearest the soft iron core is a coil of thin wire; upon this is a coil of thick wire, and the last layer again consists of fine wire. The coils with thick wire are inserted in the main current, those of fine wire in a branch current. The direction of current in the former is opposite to the direction of current in the latter. The attracting force of the electro is determined, therefore, by the difference of the electric forces in the two kinds of coils. By making use of the differential magnet the lamp can be used for divided light.

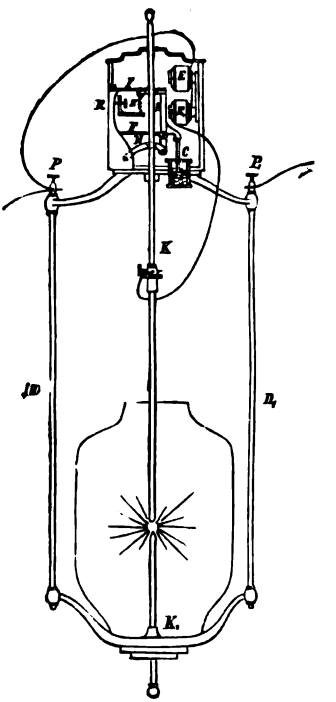


Fig. 484.—Weston-Möhring's Lamp.

We shall next consider a group of lamps in which the force of gravity moves the carbons; this motion, however, is not regulated by a brake ring, but by the catch of a clockwork and electro-magnets.

Serrin's Regulator.—To this class of lamps belongs the regulator by Serrin, constructed in 1859. The upper positive carbon-holder B (Fig. 485) has in its lower third a rod A, the teeth of which are geared with the teeth of the wheel F. Upon the same axis as F is a wheel G, the radius of which is one-half of F. From G runs a steel chain over J to an ivory piece which is connected with the lower negative carbon-holder K. At the bottom of the lamp case there is an electro-magnet E, the horizontal armature Z of which is fastened to the parallelogram R S T U. R S can turn about R, and T U can turn about T. The vertical side S U is connected with the cross piece carrying J. To prevent the parallelogram from being drawn down by its own weight, there are two springs *r* (the second is not shown in the drawing), one of which can be adjusted by means of the screw *b* and the lever *a*. The springs are so regulated that R S and T U stand horizontally. The last wheel *e* forms the spur wheel in which the three-cornered

click *d* catches. When the upper carbon is drawn up, as, for instance, for the purpose of fixing a carbon, the wheel F only will be in motion, the rest of the clockwork being at rest. The arms *x* and *y* with their screws serve for the exact adjustment of the upper carbon. The current flows through the

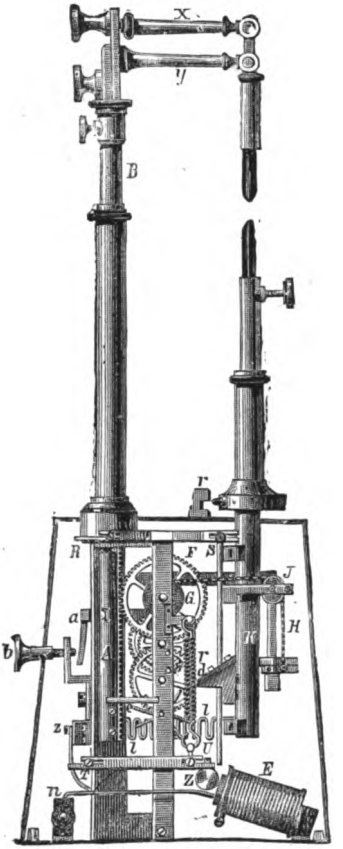


Fig. 485.—Serrin's Lamp.

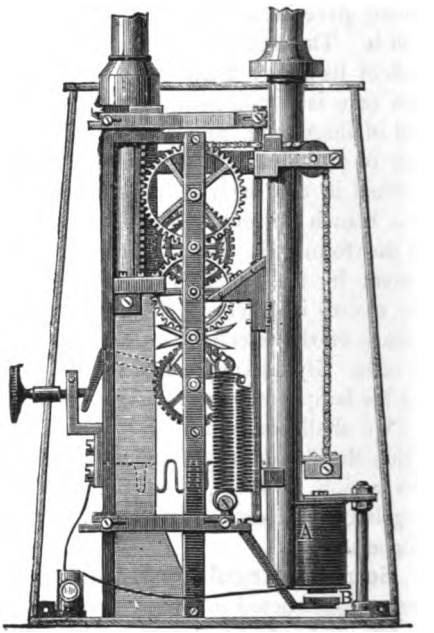


Fig. 486.—The Serrin-Lontin Lamp.

metal portions of the lamp into the carbon-holder B, through the carbons to K, through the spiral *l l* to the clamp Z, which is connected with the electro-magnet E. When a current passes through the lamp, E attracts its armature Z, and the side S U of the parallelogram descends and carries with it the lower carbon-holder. The upper carbon-holder B is raised by means of its connection with the wheel F. The carbons are thus separated and the arc formed. In spite of its weight, the upper carbon-holder cannot fall on the lower, as the click *d* catches in the spur wheel *e*, and arrests the clockwork.

The resistance increases with the consumption of the carbons, and as the current becomes weaker so the electro-magnet becomes weaker. The springs, therefore, come at length again into action, and push the parallelogram upwards, causing the click *d* to be raised, and the clockwork to be liberated. The carbon-holder B now sinks, and G is raised by means of the wheel F; the chain H now raises the lower carbon-holder K, *i.e.* the two carbons are brought near to each other once more.

Lontin modified Serrin's regulator by placing the electro-magnet A in a branch circuit, and not in the main circuit, as shown in Fig. 486. An arrangement is here shown which enables the regulator to be used for divided light also, the position of the electro-magnet and the form of armature being the same. If the lamp is to be used with alternating currents, the diameters of the wheels F and G have to be the same, for the two carbons are consumed at the same rate, and not in the proportion 1 to 2, as in Fig. 485.

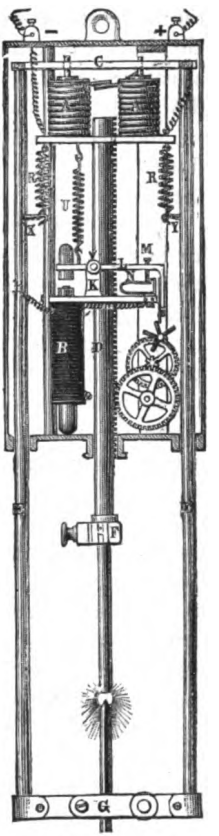


Fig. 487.—A Gramme Lamp.

Gramme's Branch Circuit Lamp.—In the branch circuit lamp by Gramme (Fig. 487) D carries the upper positive carbon, and the weight of D serves as a motor for producing the motion of the latter; the negative carbon is fastened to a cross piece G, which is connected with two rods E E; these have at their upper ends the wrought-iron bar C, which serves as an armature to the electro-magnet A A, which is inserted in the main current. The electro-magnet B is inserted in a branch circuit of great resistance, its armature is fastened to the lever L movable about V; S is a click which falls in with a spur wheel. U is a spring which tends to pull off the armature from B, N is a contact spring, and M a contact pin. The action of the lamp is as follows: When the lever L, to which the click S is fastened, is at rest, S is moved upwards, through the action of springs R R and the joints X Y, and the spur wheel is set free; D will therefore be depressed until the two carbons touch each other. The current will enter at the + clamp, will then flow through the metal parts of the lamp, through the carbons, through the rod E, to the electro-magnet A A and to the — clamp. At P there is a branch circuit, carried from the main current, which flows round the magnet B without passing the arc. The current will flow through the pin M, through the insulated contact spring N, through the magnet A and at P back again to the lamp. Whenever a current passes through the lamp the electro-magnet A A attracts C, forcing the rods E E downwards, and with them the lower carbon, thus striking the arc. The lower

carbon remains in this position while the lamp is burning, and by means of the fall of the rods E E, and the spring U, the click S is made to catch in the spur wheel, and to prevent the descent of the upper carbon-holder D. The electro-magnet B is very large, and the coils of it possess a high resistance. As the carbons are consumed the resistance in the circuit increases, consequently the current in the main circuit becomes weaker, but that in the branch circuit is strengthened. This continues until the electro-magnet B attracts its armature, setting the spur wheel free, and allowing the carbon to sink farther down; but at the same time contact is broken with the spring N and pin M, and the current through the magnet ceases. Now, therefore, the spring U draws the armature off again, the clockwork is arrested and further descent of the carbon prevented. The lamp is used both for single and divided lights.

In the lamps we have to consider next, the motion of the carbons is brought about by the weight of the carbon-holder, but the regulation is effected by a magnetic brake. To this group belong the lamps by Crompton, Burgin, Gülcher, Hauck, etc.

Crompton's Regulator Lamp.—The lamp which Crompton exhibited at Munich is shown in Fig. 488. The principal electro-magnet G G is inserted in the main circuit, and the auxiliary magnet C C in a branch circuit. When the two carbons touch each other the current flows through the electro-magnet G G, attracting its armature and raising the upper carbon-holder a little by means of the wheel R, so completing the circuit. By increasing the resistance in the arc, a branch current will be made to flow through the electro-magnet C C, which will now attract its armature and take off the brake *f* from the wheel. The wheelwork is set free, and the upper carbon is allowed to descend. At the same time the lower carbon is raised because the two carbon-holders are connected with each other by means of the string *p*, which runs over the pulleys R. By this arrangement the point of light during the time the lamp is burning is kept at a constant height.

Gülcher's Lamp (Fig. 489) is intended for divided light, although it has neither branch circuit nor differential coils. The upper positive carbon is fastened to the iron rod F, which is connected with the negative carbon-holder by means of a string and pulleys, in such a manner that it has to move through twice the distance of the lower carbon-holder. Two pulleys are fastened to an axle, the diameters of which are in the proportion of 1 to 2; the string of the positive carbon-holder runs over the larger, and the string of the negative carbon-holder over the smaller pulley. D is an electro-magnet movable about C; K is a spring which presses against the electro-magnet, tending to turn it in the direction of L. H is a block of soft iron, J a piece of wrought iron fastened to the spring E. The electro-magnet has semicircular poles at J, and on the opposite side. At J the shoe reaches over a portion of the lower side of the magnet. The screw A is connected with the positive pole of the source of electricity. The current, flowing through B to the metal ring C through the coils of the electro and its iron core, and then through the iron

rod F and both carbons, reaches the screw G, which is connected with the negative pole of the source of electricity. As soon as the circuit is completed D attracts F, but is attracted at the same time by the soft iron piece H;

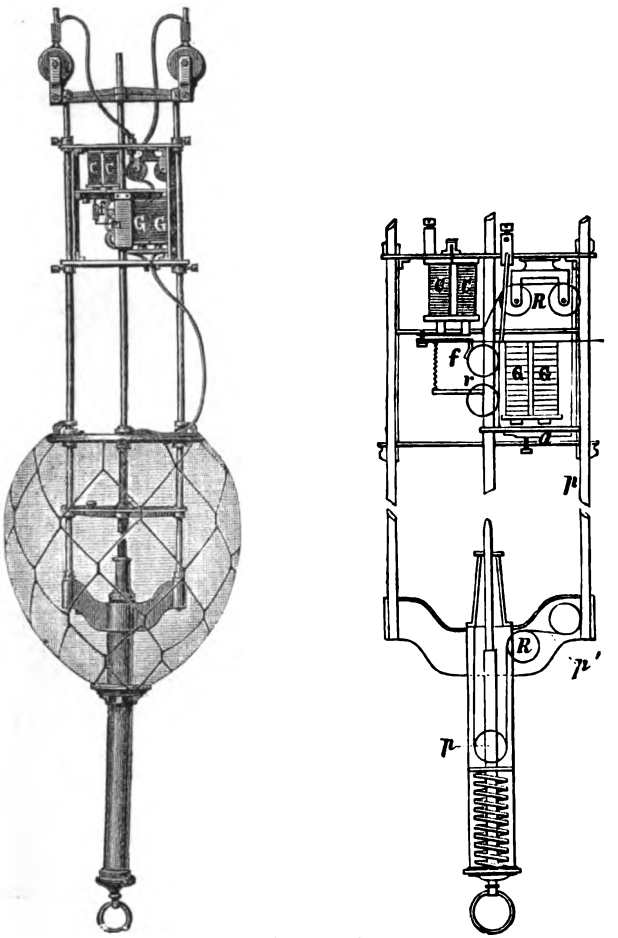


Fig. 488.—Crompton's Lamp.

the consequence is that the magnet turns about C, so that the upper carbon-holder F is pushed upwards, and the lower carbon, being connected with F, is depressed, *i.e.* the carbons are separated to form the arc. Through increase of resistance in the circuit the magnet loses power, and the force with which it attracts H becomes less and less. Finally, the weight of the upper carbon-holder overcomes the attraction of H, and the magnet turns in the opposite direction, until it is arrested at L, causing the carbons to approach each other. To prevent

violent oscillations of the magnet when the lamp is lighted, etc., the pole opposite to F has the magnetic brake at J, so that the force of the soft iron piece

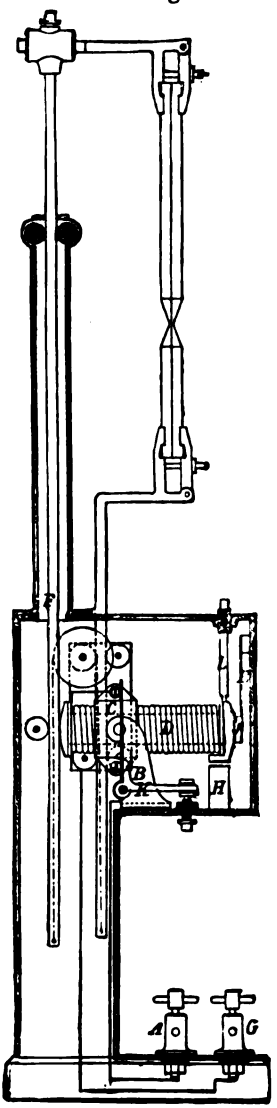


Fig. 489.—The Gülcher Lamp.

Fig. 490.—Hanging Lamp.

will correspond to the force of the magnet at various periods, causing it to move uniformly. The carbon-holder and the shoe touching it are further provided with a brass jacket.

The whole of the mechanism in the lamp shown in Fig. 490 is arranged above the carbons, so as to be used for rooms, etc. No variations are to be observed in the light of this lamp; it is almost white, and free from any tint of violet, which is common to the lights obtained by currents of low potential.

Let us next show how this lamp can, in spite of its simple construction, be utilised for divided light. Let us assume that two lamps (A and B, Fig. 490) are to be inserted into a circuit in succession. At first, when the lamp A, having its branch circuit closed, is burning, the circuit of the second lamp B is closed, so that the current coming from the machine will have to divide; one branch of it will flow through A, and a second branch through B. In B the carbons touch each other, and therefore the resistance here will be less than in A, where the current has to overcome the considerable resistance of the arc; it follows, then, that the electro-magnet in B must be powerful enough to separate the carbons. At the same time the current in A becomes weaker, and the carbons are allowed to approach each other. The conditions are now reversed; the carbons are brought nearer to each other in A, and separated farther from each other in B, so that the magnet in A is strengthened while the magnet in B is weakened. Again, the carbons in A are separated, and those in B brought near to each other. And this is continued until equilibrium is effected in the two lamps, which generally takes place in a short time. It is evident that a third lamp C may be inserted, with a similar process of oscillation, and will be in equilibrium with the two first lamps considered as a whole, and so on.

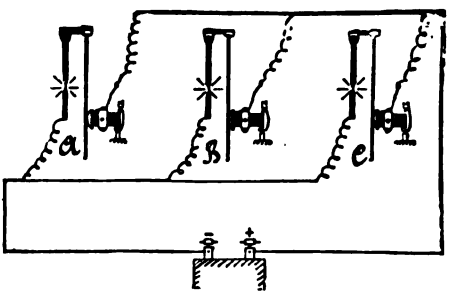


Fig. 491.—Connections of Gülcher Lamps.

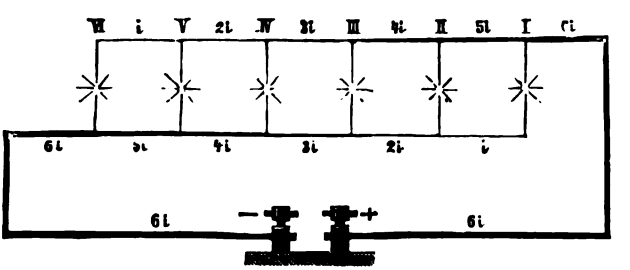


Fig. 492.—Arrangement of Circuit on the Gülcher System.

Uniform distribution of current for the several lamps may be brought about by parallel joining, if in any portion care is taken that the cross section of the conductor corresponds to the strength of current required at that particular portion. In order to obtain this a bundle is made up of as many wires as there are lamps; the wires are all of the same strength, and correspond to the strength of current. Suppose the bundle consists of six wires, denoted by $6i$; it is connected with one pole of the machine (Fig. 492), and is then conducted to the first

lamp; here one wire is allowed to branch off, and the remaining 5 *i* are conducted to lamp II; here again a wire branches off, and the remaining 4 *i* are then conducted to lamp III, and so on until lamp VI is reached, where only one wire remains. A second bundle, exactly like the first, is connected with the other pole of the machine, and conducted in the same manner to the several lamps until only one wire is left for lamp I. The intensity of current will diminish therefore with the cross section of the conductor; and the division of the light is here brought about by parallel joining. This system of lighting is distinguished by the safety of its lamps, which are not only simple in construction but low in price. A light free from violet discolorations is produced even by currents of low potential, and when several lamps are inserted in the same circuit. The parallel arrangement, however, requires more conducting material than a serial arrangement.

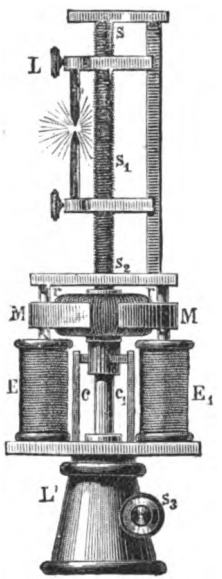


Fig. 493.—Tschikoleff's Lamp.

Tschikoleff's Lamp.—We will now consider lamps in which the regulation is brought about by an electro-motor. For this purpose we shall select the differential lamp by Tschikoleff. Although the lamp has not been very much used, it may be considered as the first so-called differential lamp. It is represented in Fig. 493. E represents an electro-magnet with thick wire coils, E_1 an electro-magnet with coils of thin wire: M M are the semi-circular poles of the two magnets, which surround two-thirds of the circumference of the Gramme ring *r r*. The contact brushes are fastened to $c\,c_1$. The axis of the Gramme ring is continued upwards from S_2 to S_1, the thread of the screw turns from S_1 in one direction to S, in the other to S_2, and the carbon-holders form the female screws. When the lamp is to be used with alternating currents, the distance between the threads in both screws is the same. Screw S_3 serves to raise or lower the arc, which is of importance when a reflector is to be used. The current enters the lamp at L; two ways are then open to it; one portion flows through the carbons and thick wire coils of the magnet E, and leaves the lamp at L_1; a second portion flows from L through the thin wire coils of the magnet E_1, and leaves the lamp at L_1. The current which flows through the arc has open to it, besides the way through E, another through *c* and the brush of the Gramme ring through c_1 and back to L_1, so that there are three branch currents flowing through the lamp. When the lamp is inserted in a circuit, the greater portion of the current will flow through the carbons touching each other, then through part of the coils of the electro-magnet E, and so through a portion of the Gramme ring. The coil E, on account of its high resistance, will have an almost imperceptible current flowing through it. In the Gramme ring poles are formed, the connecting line of which stands perpendicular to the connecting line of the two magnet poles M M.

The strongly magnetised pole M will cause the ring to turn so that the carbons are separated from each other. As the carbons are consumed the resistance increases, and therefore the current diminishes. The current increases proportionately in the branch circuit to which the electro-magnet E_1, with the fine coils, belongs, until the pole of the latter becomes more powerful than that of the former, and causes the Gramme ring to turn in the opposite direction; in other words, the carbons are brought near each other. The Gramme ring, and with it the distance between the carbons, is dependent upon the differential effect of the magnetic forces of the two electro-magnets E and E_1. To move the Gramme ring, one of the magnetic poles must have attained a certain strength, that is to say, a certain power is necessary to turn the ring, because the friction which takes place in the screw has to be overcome by the attractive force of the magnet. The length of the voltaic arc, therefore, does not remain absolutely constant.

Lacassagne and Thiers used the pressure of fluids for the regulation of the arc as early as 1855, but no workable results were obtained until quite recently, when Sedlaczek and Wikulill constructed their lamps for ships and locomotive engines.

Sedlaczek-Wikulill's Regulator Lamp.—The regulating mechanism in these lamps consists of two vertical cylinders containing glycerine, in which

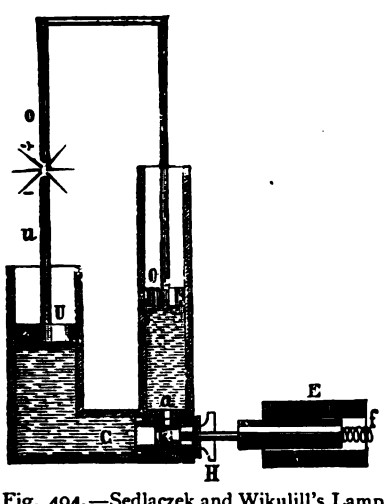


Fig. 494.—Sedlaczek and Wikulill's Lamp, with Magnet.

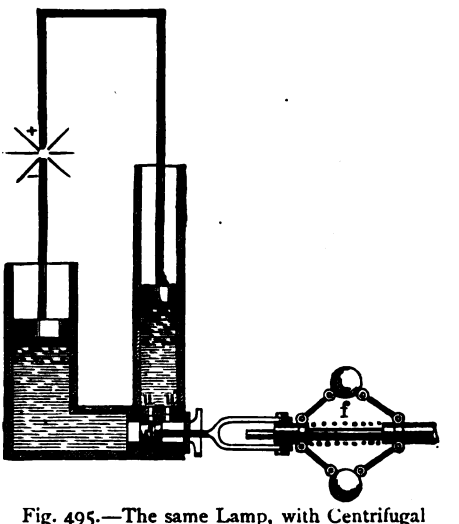


Fig. 495.—The same Lamp, with Centrifugal Governor.

are two air-tight pistons moving in such a way that when the one rises the other sinks; this motion is brought about by either using an electro-magnet or by means of a centrifugal regulator. Fig. 494 represents a section of a lamp with its electro-magnet, and Fig. 496 the perspective view of the same. The carbon-holders *o* and *u* are fastened respectively to the pistons O and U; the diameters of the latter are so arranged that O carrying the positive carbon moves through

twice the distance of U carrying the negative carbon. The result of this arrangement is that the point of light remains in the same position—a condition which is necessitated by the lamp having a reflector. The piston O presses upon the fluid, and by doing so raises the piston U; this motion will continue until the two carbons touch each other, which will close the circuit, and set the electro-magnet E in action. By means of its iron core the latter pushes the piston K out of aperture H in the horizontal tube which separates the two vertical cylinders from each other. In consequence of this moving back of the piston K the fluid beneath the piston U sinks a little, thus forming the arc. When the resistance in the circuit increases the magnet E becomes weaker, and the spring *f* presses the piston K back again into H, and communication is again restored between the two vertical cylinders. The piston U sends more fluid under O, and the two carbons approach each other until their distance becomes so small that the magnet attains its original strength, and by attracting its iron core again cuts off communication between the two cylinders.

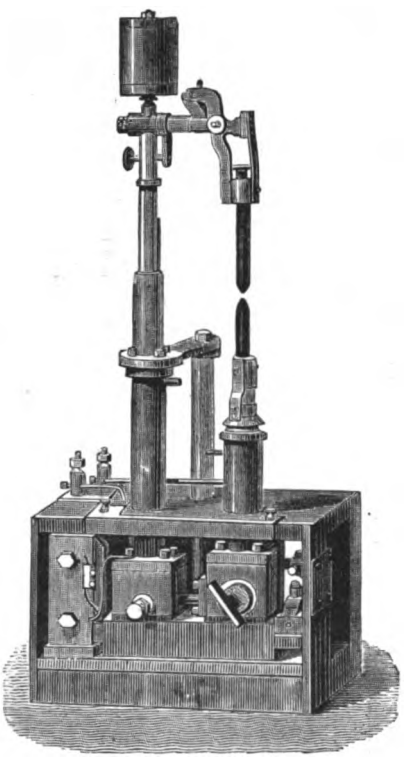


Fig. 496.—Sedlaczek and Wikulill's Lamp.

Fig. 495 represents a lamp with a piston *d* connected with a centrifugal regulator, which is made to revolve either by means of the light-producing machine, or by a motor. When the machine is started, in consequence of the divergence of the balls of its regulator the piston *d* is pushed out, stopping communication between the two cylinders; the lower carbon sinks and the arc is formed. The burning away of the carbons causes a greater resistance, and weakens the current in the circuit. This causes the machine to move with greater velocity, for when the current becomes weaker the attraction between the rotating armature and the fixed inductors becomes lessened, and thus the work to be done by the motor which turns the armature is lessened also; the motor therefore then moves with greater velocity. Through the increased speed of the machine and its regulator the piston *d* is pushed out farther still, until with a corresponding length of the arc a second opening *u'* is reached, and with it communication between the fluids again established, causing the carbons again to approach each other. The current becomes stronger again, the machine rotates more slowly, and the regulator, by pressing *d* inwards, again closes the opening.

Solignac's Regulator.—Solignac uses the heat produced by the voltaic arc for the regulation of his lamp. Fig. 497 shows at top the lamp ready for use; and below, its construction. The carbons K K_1 are 50 centimetres long, and arranged horizontally; they are moved towards each other by means of two spring cases F, and chains or strings S which run over the pulleys R. The carbons are fastened to the pulleys R, which move between the guide-bars T T_1. The carbons have at

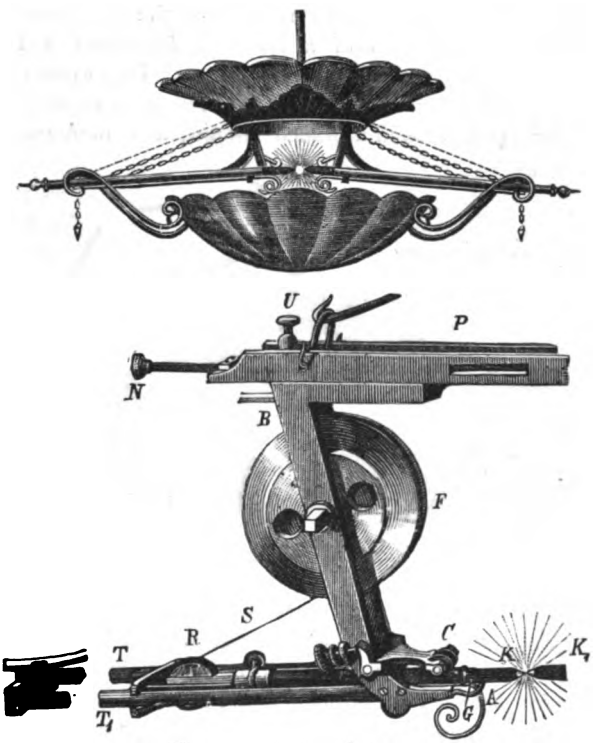


Fig. 497.—Solignac's Lamp.

their lower sides small glass rods G, the ends of which press against the nickel joints A, the position of which may be adjusted by means of screws. The current enters through the clamp U, passes through the contact rollers C, and enters the carbons very close to the voltaic arc, so that while the lamp is burning it need only go through a few centimetres of carbon. The whole is held in position by means of the plate P and the click B, which serve at the same time for the conduction of the current. By turning the screw N the distance between the two halves of the lamp can be diminished or increased, and by means of this arrangement the arc is formed; at present this is done by hand. The tendency of the carbons to approach each other is counteracted by the glass rods, which

touch the nickel joints at A. The joints, being in the immediate neighbourhood of the arc, cause the glass rods to become soft through the heat and to bend, as shown in the figure, their bending being due to the pressure of the spring F, which tends to draw the carbons together.

Schmidt's Regulator.—In the lamps by F. Schmidt the length of the arc is regulated by electro-magnetic or electro-dynamic repulsion or attraction. The four coils A, B, C, D (Fig. 498) are fastened to the arms of two levers, which cross each other, and are capable of turning about the point where they cross each other. Each coil consists of a layer of thick and a layer of thin wire, which are perfectly insulated from each other. The wires are connected with the clamps, so that the thick wires and the carbons K K_1 are inserted in the main circuit, and the thin wires in a branch circuit; and, moreover, so that the

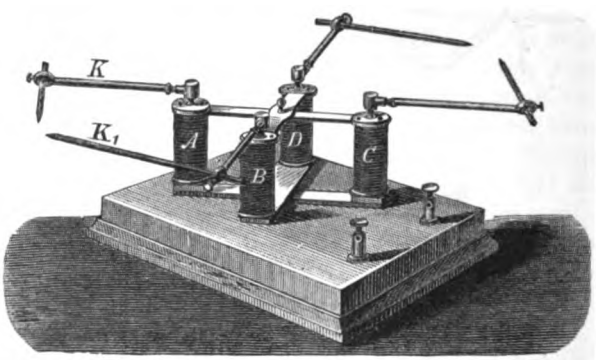


Fig. 498.—Schmidt's Lamp.

two coils A and B as well as C and D repel each other when the current passes through the turns of the thick wire, but attract each other when the current flows through the thin wire. A and D, B and C will be oppositely influenced, *i.e.* motion due to the attraction between the bobbins A and B, C and D will be favoured by the repulsion betwen B and C, A and D. When the carbons K K_1 do not touch each other, the whole current will flow through the thin wires, and will cause attraction between the coils A and B, C and D, and repulsion between the coils B and C, A and D, and so the carbons will be brought to touch each other, thus completing the main circuit. The current now will divide into two portions, the larger portion flowing through the main circuit, *i.e.* through the carbons and the thick wires. The dynamical force of the thick spirals will be greater than that of the thin spirals; but the current in the thick wires causing repulsion between A and B, C and D, these coils and their carbons must separate. The arc is thus formed, and with it a new resistance inserted in the circuit; the resistance increases proportionately to the consumption of the carbons, causing a gradual increase of the current in the branch circuit until the two carbons are again made to approach. Regulation is due, therefore, to the opposing effects of the two

currents flowing through the two kinds of wires. The arrangement of the coils may be altered, but as no practical applications have as yet been obtained for this kind of lamp, we only describe one specimen.

ELECTRIC CANDLES.

Here the size of the voltaic arc is not made constant by any mechanism, but is fixed once for all by construction. The parallel position of the carbons and their gradual consumption gave rise to the name "electric candles." The first commercially practical candle was constructed by Paul Jablochkoff in the year 1876. Werdermann was, however, his predecessor; the invention of the latter, although he did not intend it for electric lighting, but to serve as a kind of borer for rocks, was constructed on the same principle. Werdermann allowed an arc to form between two carbons parallel to each other, but separated from each other by a layer of air; and caused a current of air or steam to pass between them. The effect was similar to that produced by a blow-pipe, but of such high temperature that in a few hours the hardest granite was fused. The air pipe here took the place of an electro-magnet. Werdermann not only prepared the rod for the Jablochkoff and other candles, but also for Jamin, as we shall see later on.

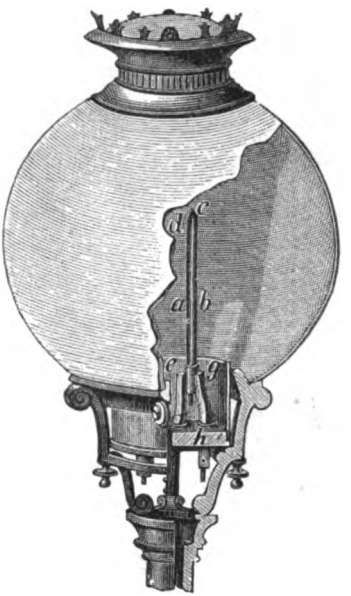


Fig. 499.—Jablochkoff's Candle.

The Jablochkoff Candle.—The candle by Jablochkoff consists of two parallel carbon rods *a b* (Fig. 499), which are separated from each other by a layer of plaster of Paris; the lower portions of the carbons have short brass tubes fastened to a plate *h*, against which two metal springs *e* and *g* press, and the current is conducted through the latter into the candle. A thin plate of graphite *c* is laid across the two carbon points, and is held in position by a paper band *d*, which serves also to light the candle. When the candle is inserted in the circuit a current passes from one of the carbon rods through the connecting piece at the top to the second carbon rod, and then back again to the source of electricity. The connecting piece becomes heated, and after it has been volatilised helps to form the arc between the two carbon rods. As the carbons are consumed the insulating layer is made to fuse and to volatilise. Since the positive carbon is consumed twice as quickly as the negative, it must have twice the cross section of the negative. This proportion is, however, not exact, and as all candles are not consumed at exactly the same rate, alternating currents have

to be used. A candle, the carbon rods of which have a cross section of four millimetres, and a length of from 220 to 225 millimetres, burns about 1½ hours, producing a light of 100-candle power. Several candles can be inserted in one circuit, the light intensity of the sum of the candles being greater than that of a correspondingly large single candle. The reason of this is, that not only is the

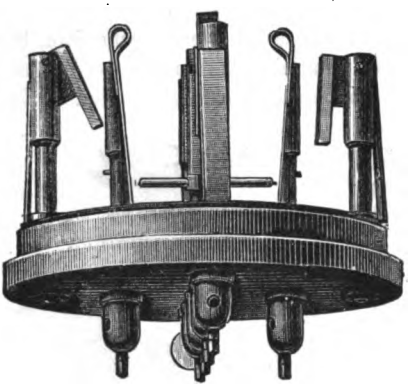
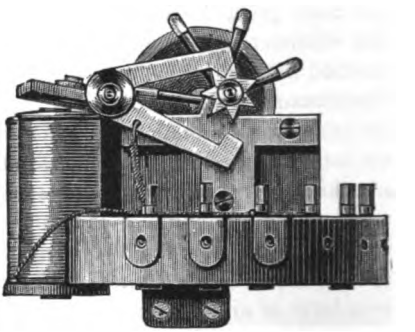
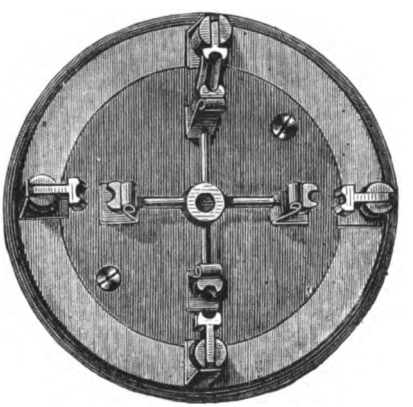


Fig. 500.—Automatic Inserter.





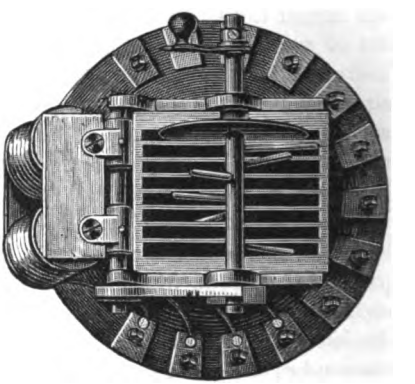


Fig. 501.—Automatic Inserter.

voltaic arc between the two carbons luminous, but so also is the volatilising substance between the carbons. When from two to five candles are inserted in one circuit, by turning a commutator one candle after another may be lighted. This arrangement is very inconvenient, and if one of the candles should go out from some cause, all the other candles in the same circuit would go out too, and could only be relighted by turning their respective commutators. To prevent this, the mechanical contrivances shown in Figs. 500 and 501 have been devised. Upon a ground plate of transparent material, four pairs of clamps are arranged to receive the four candles of the lamp and conduct the current; the

inner four have thermostatic pieces of steel and copper attached, which become strongly heated. When the candle has burned down these bend, owing to the fact that the two metals have different coefficients of expansion. This brings the strip of two metals into contact with the opposite metal pin, forcing the current to flow through the candles and through the coils of an electro-magnet, as shown in Fig. 501. The latter attracts its armature, which causes a toothed shaft to turn by means of a catch and spur wheel connected with the armature. Underneath this shaft is placed a box of gutta-percha, divided into as many

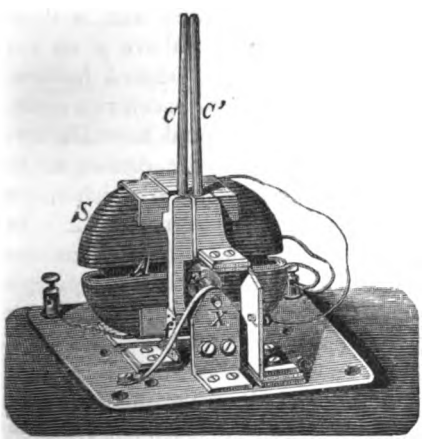


Fig. 502.—Morin's Candle.

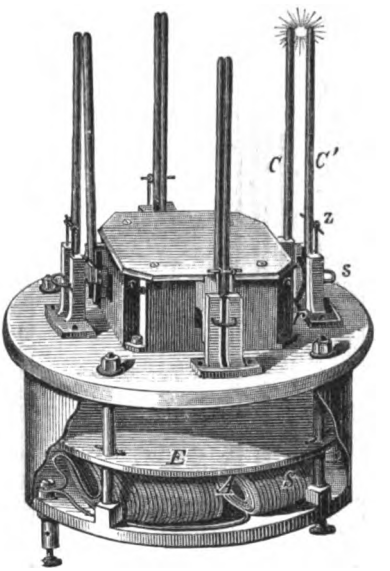


Fig. 503.—Lamp with Four Candles.

portions as there are candles. These portions are filled with mercury, and connected with the several candles. The electric current enters the shaft and flows through the comb of the shaft, dipping into the mercury, then through the candle connected with the mercury, and back again to the machine. The turning of the shaft causes the immersion of the next tooth and the insertion of another candle. Meanwhile the metal strip of the candle that has been consumed has cooled, and contact is broken, so that the current ceases in the magnet, the armature falls off, and the catch prevents the moving of the cog-wheel. Although this contrivance prevents the extinction of the lamp, it does not ascertain whether the candles have ceased burning.

Instead of using solid insulating substances between the carbons, air has been used, and the candles have been made movable. Such were the candles by Wilde, Morin, Jamin, Siemens and Halske, etc.

Morin's Electric Candle.—Fig. 502 represents an apparatus by Morin;

the carbon C is movable, C′ is fixed. A is movable about the axis X inside the solenoid S. The excentric E is fastened upon the axis X, which slides with its circumference against the carbon-holder of C, which is held by the spring plate *f* and pressed against E. As long as no current passes through the lamp the two carbons touch each other; when, however, the current enters, A moves with the excentric and separates the carbons, thus forming the voltaic arc; should the candle go out from any cause it turns the excentric in such a manner that the two candles again touch each other, again closing the circuit. If the lamp has to burn for long, more than one candle must be provided. Fig. 503 represents a lamp with four candles. Here the solenoid is horizontally arranged and A turns about a vertical axis; above A on the same axis a disc is fastened horizontally, which has four excentrics corresponding to the several movable carbons C. To bind the carbon to its holder zinc wire is used, which melts when the candle has reached Z. In order to break the circuit when the candle has been consumed, the spring *r* pushes the carbon outwards so that it falls against the wire loop *s*; A now turns, and the next excentric is brought into action and causes the following couple of carbons to touch one another.

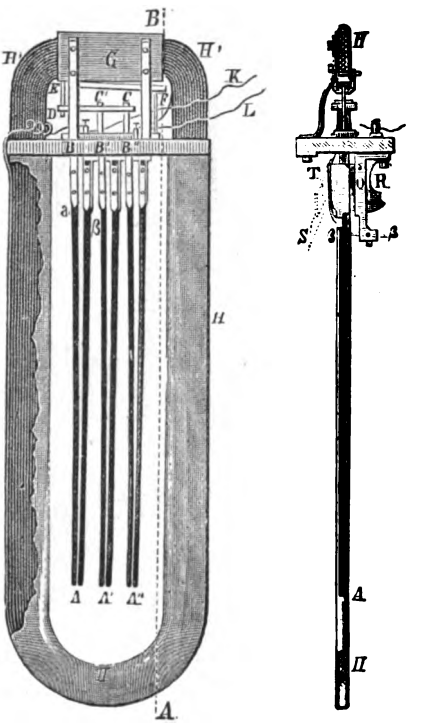


Fig. 504.—Jamin's Candle.

Jamin's Electric Candle.—Jamin also uses carbon rods insulated by air from each other; but he further surrounds the candles of his lamp with wire H (Fig. 504), through which a current is sent to force the voltaic arc towards the ends of the candles, where it is maintained. The carbons A A′ A″ are fixed, B B′ B″ are fastened to the cross piece C C′, which is connected with the iron plate E F by means of the rod D E; opposite to C C′ is the soft iron piece G, which becomes magnetised whenever a current circulates through the so-called reaction coil H H. If G is demagnetised (that is, if the lamp has no current going through it) the plate E F assumes its lowest position and presses with its weight against the carbons of the several candles, or, more correctly, presses the two longest carbons into contact with each other. When a current is sent through the wires K L, it flows through the reaction coil, and then through the carbons that touch each other; G becomes magnetised, attracts E F, separating the carbons, and forming the arc in the couple which touched each other. When the current is

interrupted E F again falls off from G, and causes the two carbons to touch each other once more, so that the arc will be formed between them when the current is again passed through the lamp. If a candle is totally consumed the next one is automatically inserted in the following manner: A zinc wire which is movable is fastened to V against the fixed carbon, and is pressed by the spring R. (*See* the cross section.) If the candle has burned down to the zinc wire the latter melts off, and the spring R presses against O, giving the carbon a different direction and causing the candle to go out. The next candle is now made to burn in the way already described. Jamin's candles, in spite of their ingenious arrangement, are commercially of little value. The candles have to be used with alternating currents, and require some kind of regulating apparatus, nor can their arrangement be called simple as compared with regulator lamps; besides, the light obtained from the arc of a candle is considerably less than that obtained by a regulator lamp; the proportion according to Tresca is as 3 to 7.

LAMPS WITH CARBONS INCLINED TOWARDS EACH OTHER.

William Edward Staite took out patents for several lamps (1846) having carbons inclined at an angle, one of which is shown in Fig. 505. Two carbon rods are so arranged as to meet a bar of some substance capable of resisting the high temperature of the arc without altering the angle. Staite's lamp has been modified by Gérard, Lescuyer, Hedges, Rapieff, Clerc, and others.

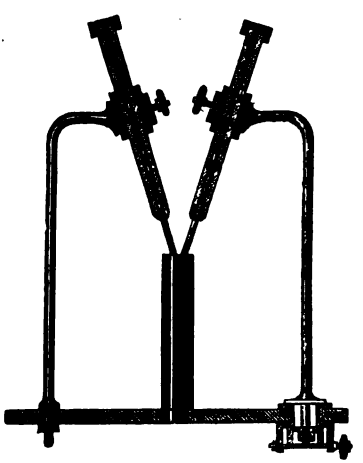


Fig. 505.—Staite's Lamp.

Rapieff's Lamp.—Fig. 506 represents a lamp by Rapieff. The two rods s s' upon which the carbon-holders *d* and *d'* are arranged, are fastened to a ground plate, and each carbon-holder has two carbons *a a'* and *b b'*, forming acute angles with each other, which are kept in this position by means of copper pulleys. The ends of the carbon away from the arc have strings fastened to them which are connected with a counter-weight w. The carbon-holder *d* and the rod s' are insulated from the remaining portions of the lamp; *d'* is movable about the hinge *g*, but the carbon-holder *d* is fixed. The screw *h* serves to raise or lower the voltaic arc. The carbon couples are independent of each other; one couple may be consumed more quickly than the other, yet the carbons will advance in such a manner that the two couples meet at one point, an arrangement which has the advantage of allowing continuous currents to be used. When the lamp is inserted in the circuit the current passes through an electro-magnet placed at the foot of

the lamp; the electro attracts its armature, pulling down a rod going through *s*, and thus forming the arc. When the lamp goes out the current through the magnet ceases, and the carbons approach each other again. In order that when one lamp goes out all the lamps in the same circuit shall not be extinguished,

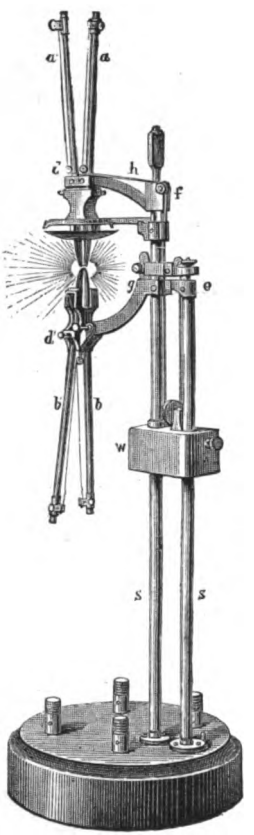


Fig. 506.—Rapieff's Lamp.

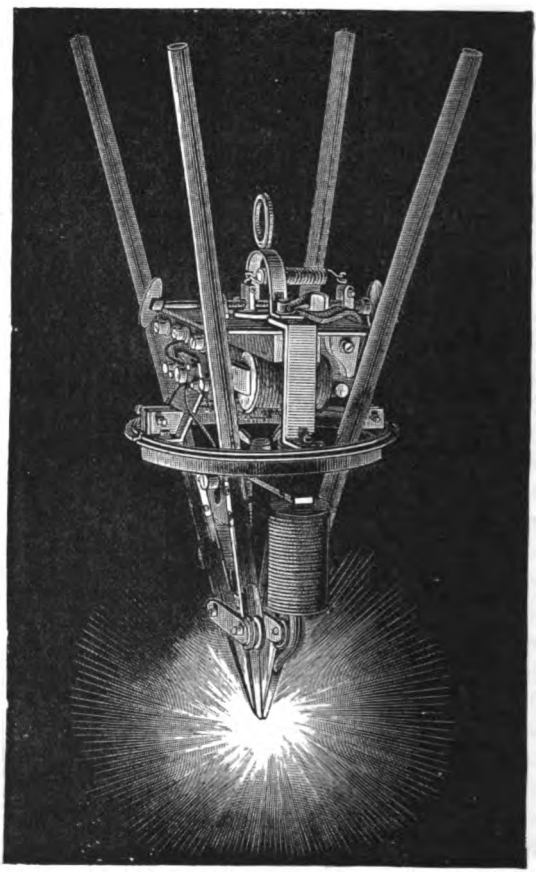


Fig. 507.—Gérard's Lamp.

the electro-magnet is so arranged that when no current passes through its coils to the lamp, it forms a branch circuit where a resistance corresponding to the resistance of the lamp is inserted.

Gérard's Lamp.—Gérard also uses two carbon couples in the construction of his lamp; the carbons are so arranged that they form the edges of a pyramid (Fig. 507). They are placed in tubes, and the current is conducted by means of contact rollers fastened near the points of the carbons. The carbon

couple to the left of the figure is fastened to a ground plate, while the other couple (to the right of the figure) can move about a joint. An electro-magnet is placed underneath the ground plate, and its armature is fastened to the tubes of the right carbon couple; the coils of the magnet are inserted in a branch circuit. Underneath this another magnet, the armatures of which are bent and directed against the voltaic arc, is arranged and inserted in the main circuit.

Clerc's Soleil Lamp.—The lamp constructed by Clerc is known under the name of the Soleil lamp. One of the earliest models is shown in Fig. 508. Two carbons A and B are introduced into holes drilled in a marble block. The block is carried by the case G G, with which it is connected by means of screws. D D, inside the case, are copper wires, which serve as conductors for the current and also hold the carbons. The lamp is inserted in the circuit by means of

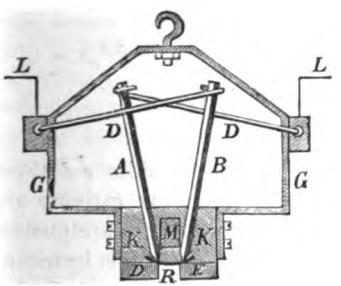


Fig. 508—Soleil Lamp.

Fig. 509.—Street and Maquaire's Form of Soleil.

wires L L, and is lighted by the help of a small piece of carbon R. The current enters at one carbon, flows through R and leaves the lamp through the second carbon. R becomes heated and evaporates, thus forming the arc; at the same time the portion of the marble block between the carbon points becomes luminous and increases the arc light. In proportion as the carbons are consumed they sink down by their own weight. In later constructions it was thought more convenient to form the block of several parts. The two pieces K K consist of chalk, D E of granite, and M is a piece of white marble; the several parts are held in position by means of a case and screws. The plan has this advantage, that when the marble block which takes part in the production of light has become useless, it may be replaced without having the other portions altered.

This somewhat primitive arrangement has been gradually modified. The form given to it by the engineers Street and Maquaire is shown in Fig. 509. The prismatically shaped marble block, which measures only 3, 4, and 5 centimetres, is scooped out to hold the carbons B and C of about 20 millimetres thickness. A canal of 5 millimetres wide connects the scooped openings with each other. This canal is funnel-shaped on one side. A the arc is formed in the funnel, when the current flows from B to C through the narrow channel;

the funnel serves at the same time as a reflector. The carbon C has a bore through its whole length intended for a thin carbon pencil D, the lamp-lighter. The working of the lamp may be better understood with the help of Fig. 510.

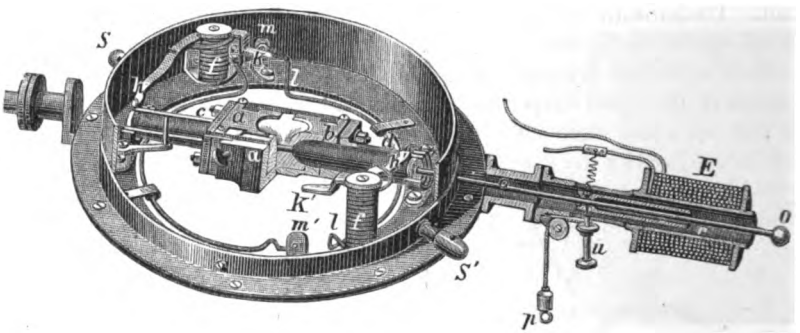


Fig. 510.—Mechanism of Street and Maquaire's Lamp.

The marble block is enclosed in an iron box *a b*, and at its sides *c d* there are tubes intended for the carbons. Through these tubes the carbons are placed in the bell-shaped cavities of the marble block. The carbons are pushed against each other by means of the spiral springs *f f*, turning the arms of the bent lever *h h'* so that they press against the free ends of the carbons and tend to push them towards the middle of the lamp. The tubes *c* and *d* have slits in order to allow of the forward motion of the levers. The arms *k k'* of the lever are turned by the springs *f f*, so that they come in contact with *m* or *m'* as soon as either of the carbons is consumed, and thereby the lamp is put out of circuit. The lighting is brought about as follows: The thin carbon rod D (Fig. 509) is fastened to a metal rod *o o* (Fig. 510) which is clamped by means of the screw *u* to the iron tube *r*; a little weight *p* moves the rod *o*, with its carbon rod and tube, through the narrow canal of the marble block, until the carbon touches the carbon B (Fig. 509). The tube *r* is inside another tube, which has at E a solenoid, through the coils of which

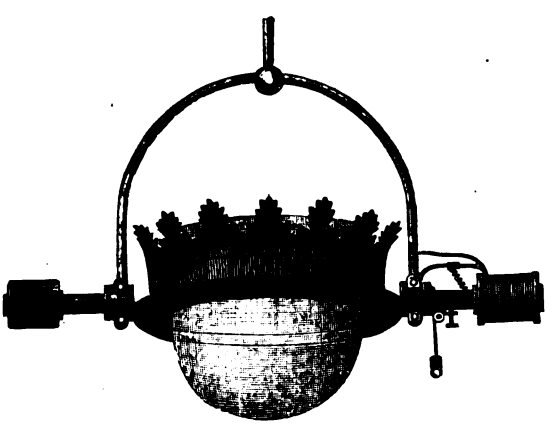


Fig. 511.—Soleil Lamp.

the current passes before it passes through the lamp. The metal rod *o* is connected with the coils of the solenoid by means of a branch conductor (at screw *u*). As soon as the current flows through the coils of E the solenoid attracts the iron tube, moving the thin carbon away from the carbon of the lamp; at the same time a current passes through the branch circuit to the rod *o*, to the carbon rod, and so to the opposite carbon of the lamp, thus causing a small voltaic arc; when the carbon rod, in its backward motion, has entirely entered the hollow lamp carbon, the arc is produced between the two lamp carbons. What has been described not only takes place at the lighting of the lamp, but also when it goes out.

This lamp can be used with continuous as well as alternating currents, and produces a very steady light. Even considerable variations of current do not cause extinction of the lamp; the white-hot marble conducts the current, which must either be very weak indeed, or interrupted for some time, to cause the lamp to go out altogether. The marble block lasts at least fifteen hours, and the carbons are consumed at the rate of two millimetres per rod an hour. The normal length of the carbons is 10 centimetres, but longer pieces of carbon may also be used. According to the statements made by the engineers of the company, a lamp of 90 Carcel burners requires 1½ H.P.; and a lamp of 120 Carcel burners, 2 H.P. The price of the lamp is 200 francs, that of the carbon 3 francs per metre; lamp-lighter carbon 75 cent. per metre, and that of the marble block 75 cent. Fig. 511 represents a complete lamp.

Heinrichs' Lamp.—The lamp by Heinrichs is in principle the same as those by Rapieff, Gérard, and others, but it has bent carbons, whereby the same length is made to last for a longer period. *k k* (Fig. 512) represents the positive carbon couple, movable by means of *h h* about the points *x x* in the plane of the carbons. To the pivots *x x* are fastened toothed wheels r_1 r_1, which bring about a uniform motion of the carbons *k k*, maintaining the point of contact at the same place. The wheels r_1 r_1 are placed inside a frame which is fastened to *s*, connected with the longer arm *a* of a lever, the shorter arm a_1 of which is formed by the armature of the electro-magnet E. The

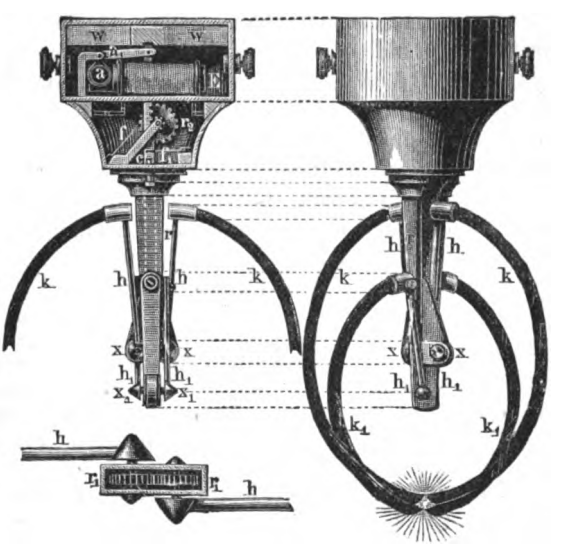


Fig. 512.—Heinrichs' Lamp.

negative carbon couple k_1 k_1 moves about the axis x_1 x_1. The wheelwork of the negative carbons is held by a larger frame r_2, which is insulated and fastened to the case of the lamp. The coil w w above the electro-magnet is automatically inserted into the circuit when a lamp is extinguished, and compensates the resistance of the arc.

CARBONS FOR ARC LAMPS AND THEIR PRODUCTION.

These various lamps can only give satisfactory results when the carbons have all the properties required. Davy used rods of charcoal for his first experiment, but soon found that charcoal was not hard enough for purposes of lighting by electricity. Foucault used retort coke, but even this substance did not answer, owing to the impurities it contained; metal particles mixed with the carbon particles will be brought to glow, melt, and then evaporate, causing the light to be coloured, the carbons to spurt, etc. etc. It was therefore necessary to manufacture carbons specially for this purpose. Without attempting to give a complete list of those who have done much towards the improvement of lamp carbons, we shall name a few.

Jacquelain's Method of Preparing Pure Carbons.—Jacquelain prepared artificial retort carbon, free from metallic impurities, from tar, which he allowed to decompose in strongly-heated furnaces. The light obtained with those carbons was 25 per cent. higher than that obtained with ordinary retort carbon; but carbons obtained in this manner are too expensive, and much labour is required to cut the very hard material into rods. Jacquelain has recently given the following receipt for the production of pure carbons: Prismatically-shaped coke rods are made white-hot, and first exposed, for at least thirty hours, to a stream of chlorine, then to the vapours of heavy coal-tar; in order to get rid of silicic acid and clay matter, the carbons are treated first with soda and then with distilled water; hydrochloric acid is used to get rid of the iron and alkaline earths. The carbons are then allowed to remain in diluted hydrofluoric acid, at 15° to 25° C. (1 vol. to 2 vols.), contained in a leaden trough, for twenty-four to twenty-eight hours, and are finally allowed to carbonise from three to five hours. Carbons that are thus purified give a far more constant light than carbons that are unpurified. The following table gives (v) the losses of the carbons in grammes during twenty-four hours, and the light intensity (h) compared with that of the Carcel lamp:—

	v	h
Graphite, Alibert	245·0	55·14
,, treated with hydrofluoric acid	232·3	115·62
Coke	183·4	71·90
,, ,, ,, soda	273·7	69·44
,, ,, ,, hydrofluoric acid	203·0	85·75

Carré's Mode of Making Lamp Carbons.—Carré, after experimenting for a considerable time, took out a patent (1876) for a process of producing artificial lamp carbons, consisting of powdered coke, calcined soot,

and a specially prepared syrup consisting of 30 parts of cane sugar, and 12 parts of gum; 7 to 8 parts of this syrup are mixed with 5 parts of soot and 15 of coke. The coke used has to be of best quality, well powdered, and well washed with water or acids. The mixture is worked into a paste, compressed, and then put through a mould in form of rods; the rods thus obtained are placed in crucibles and exposed to a high temperature for some time; after this they are boiled for two to three hours in very concentrated syrup of cane or caramel sugar. During the process the carbons are cooled several times so as to allow the atmospheric

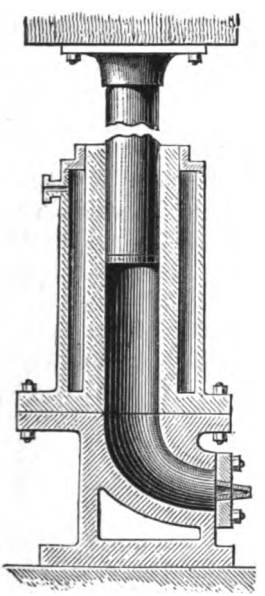


Fig. 513.—Apparatus for Making Carbons.

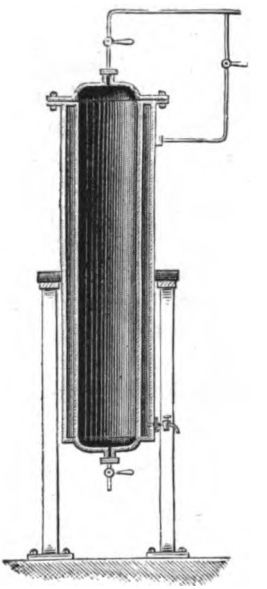


Fig. 514.—Apparatus for Treating Carbons.

pressure to press the syrup well into all the pores of the carbon. The rods are now well washed to get rid of the syrup sticking to the surface, and then again strongly heated. These operations must be repeated until the carbons have the necessary density.

Napoli's Carbons.—Napoli uses for his carbon rods a specially-prepared carbon made by dry distillation of tar. The carbon thus obtained is ground to powder between two stones; by adding a certain quantity of tar the whole is made into a paste, which is brought into moulds (shown in Fig. 513) consisting of two portions, the lower of which is bent and has three mouth-pieces; the bend is necessary because, owing to the tenacity of the mass, the pressure would not otherwise be conveyed uniformly, and the product would not be homogeneous. This cylinder is surrounded by a steam pipe for the purpose of

maintaining the mass pliable. The press is worked by a hydraulic engine. The carbons thus obtained are gradually brought to a red heat so as to decompose any tar still present: the temperature has to be gradually raised in order to give time for the gases to escape. The carbons after being allowed to cool are again heated to a higher temperature. Carbons thus obtained have a greyish or steel colour, and are sufficiently hard and dense. 75 millimetres of these carbons are used by a lamp during one hour, whilst 250 millimetres of Carré's carbons are needed. To give still greater density to the carbons they are brought into a cylinder (Fig. 514) which is surrounded by a steam jacket; the cylinder containing the carbons is then exhausted, and the fluid is allowed to enter the cylinder by means of a cock at the bottom; the latter is then closed and a cock at the top opened, which admits steam from the boiler to press the liquid into the pores of the carbon. The liquid is allowed to flow off, and steam sent through the cylinder to cleanse the carbon of any fluid still adhering to its surface. The carbons are finally heated.

When an arc is produced between two carbons, no matter how they may be prepared, not only are the carbons heated at the points, but also to a length of from 7 to 8 centimetres from the point. As this involves a loss of light, an attempt has been made to prevent it by coating the carbons with a thin metallic layer. Experiments made by Reynier in the laboratories of Sautter, Lemonnier et Cie., with Serrin and Carré carbons, show that pointing of free carbons takes place more easily than that of metallised carbons, and that the duration of burning is longer of carbons coated with copper than of those treated with nickel.

FITTINGS AND ACCESSORIES.

Engines used for Motors.—Generators for electricity have been treated at length, and we have found that machines are mostly used, and that the cases where galvanic batteries are employed are exceptional. The electric machine, however, requires some kind of motor. Simple steam engines are not very well adapted for this purpose, on account of their two dead points which give rise to irregularities; nor are all irregularities avoided by using machines with two cylinders, because the connection of the two machines is brought about by means of belts, the flexibility and elasticity of which prevent absolute regularity of motion. The machines where no belting of any kind is needed (*i.e.* steam engines with rapid rotation) are preferable for our purpose. The axis of the motor and the axis of the dynamo machine may consist of one piece, or the two axes may be directly coupled. The machines generally used are those constructed by Abraham, Brotherhood, Dolgoroucki, Gwynne, Tangye, etc. The connection of a Siemens continuous current machine with a three-cylinder machine by Brotherhood is shown in Fig. 515. Fig. 516 shows the connection of a Gramme machine with a motor by Gwynne. Gas engines may be used with advantage when motors of small power are required. A gas engine requires less attention, it takes up less room than a steam engine, and the starting and

stopping of a gas engine are much easier and sooner effected. The motors made under Otto's patent, especially those by Messrs. Crossley, of Halifax, are at present largely used, and there seems to be little doubt that gas motors will come more and more into use, especially as they are being constantly improved. The production of gases intended for fuel only is much cheaper than that of gas for lighting purposes.

To utilise water power, water wheels and turbines are used; the axes of turbines, as a rule, are arranged vertically, those of water wheels horizontally.

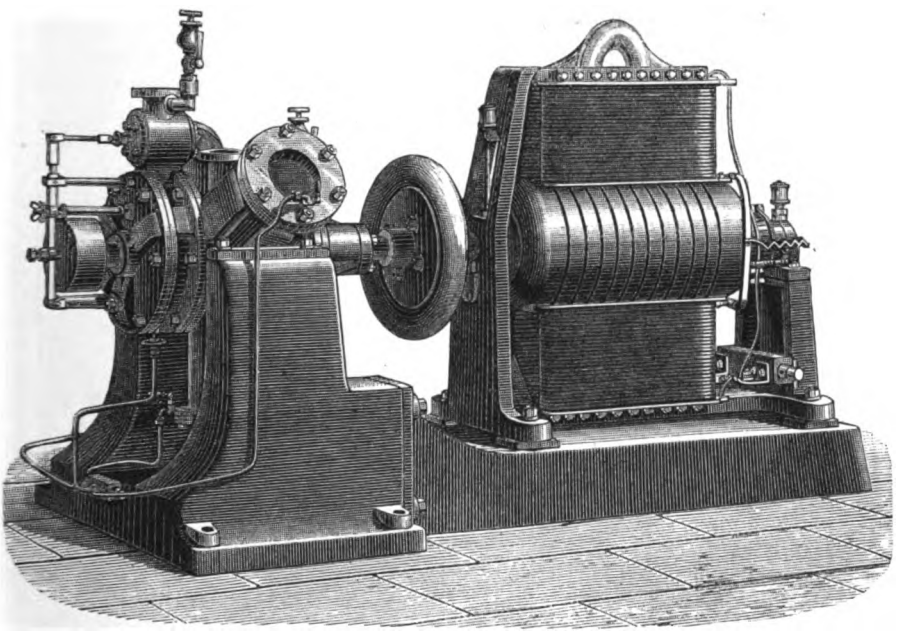


Fig. 515.—Brotherhood's Engine.

For driving dynamo machines, turbines as a rule are preferred, and practice has shown that ice very seldom causes interruption. The use of water power for electric machines has great advantages; but, of course, it can be only applied when there is a systematic distribution of water. A pair of turbines are shown in the illustration on page 633.

Kinds and Positions of Lamps for Different Purposes.—Lamps must be adapted to the purposes for which they are intended. For instance, a printing or weaving room ought to have lamps which will give a steady white light; a photographic studio ought to have a light rich in violet rays; a picture gallery, a soft yellowish light, etc. etc. The height of suspension and the distribution of the lamps depend upon the objects to be lighted; calculations and experiments have shown that the most favourable height for a lamp would

be that which is about 0·7 or 0·66 of the radius of the area to be lighted; should the nature of the locality to be lighted make this impossible, it is best to throw the light against a white ceiling and have it reflected. One lamp hung so as to form 0·7 of the radius of the circle to be lighted, and having a light intensity equal to the 450 normal candles, will be sufficient for an area of 2,000 square yards, a station hall of 1,400 square yards, a foundry of 500 to 600 square yards, weaving factory, etc., of 200 square yards, printing room, etc., of 150 to 250 square yards.

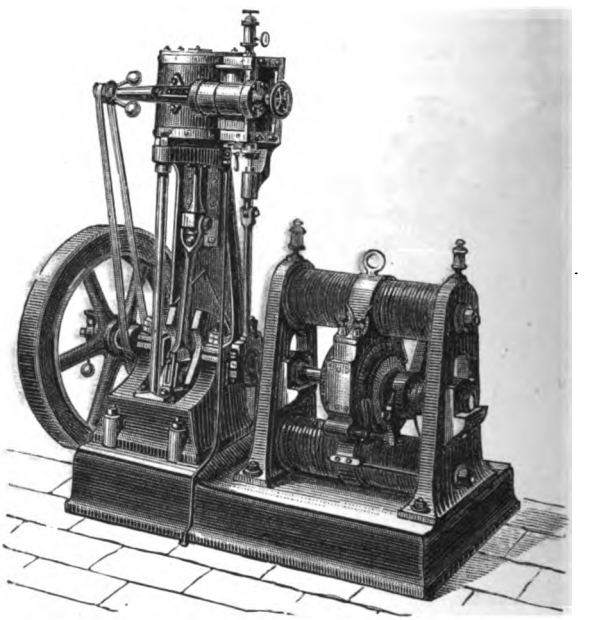


Fig. 516.—Gwynne's Motor Engine.

The globes which as a rule cover the lamps are not only used for protection, but also to prevent the casting of intense shadows. If opal or translucent glass globes are used, they become as it were sources of light, the surfaces of which compared to that of the arc are very large, and therefore incapable of casting shadows. By using these glass shades a certain percentage of light intensity is lost, which varies from 15 to 30 per cent., according to the kind of glass of which the globe is made. Certain kinds of milk glass may cause a loss of as much as 60 per cent., and for this reason should be discarded. An electrolier for glow lights, by E. Palme, Sleinschönan, Bohemia, is represented in Fig. 517.

The rules laid down by German fire insurance companies to prevent fire by electric lamps are as follows: Arc lamps are not admissible for rooms where there

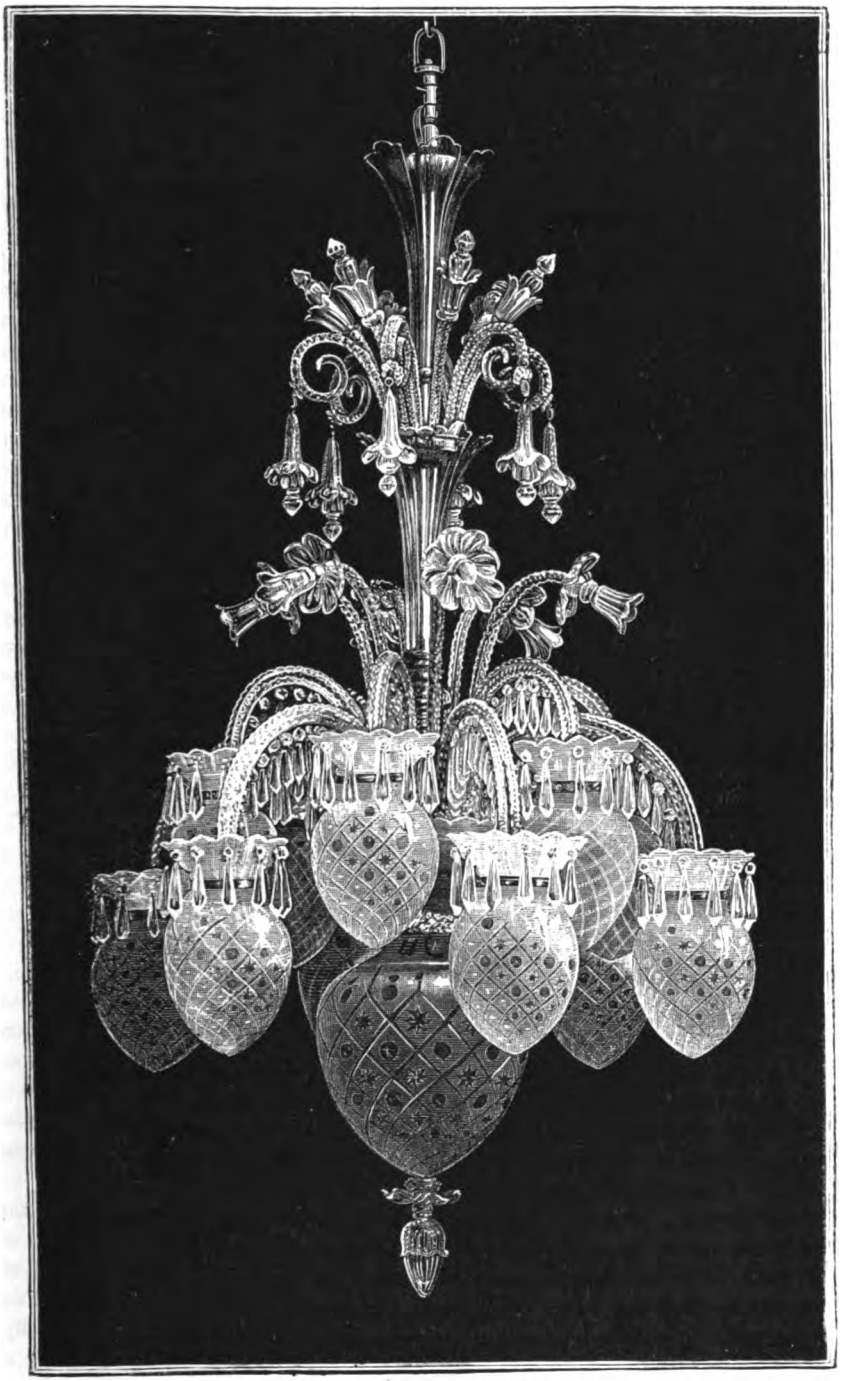


Fig. 517.—Electric Chandelier.

are explosives, or substances easily inflammable; arc lamps have to be provided with globes or lanterns that are closed at the lower end by ash plates, when used in rooms where easily inflammable substances are worked or deposited. Glow lamps may be used in all rooms, but they must be surrounded with globes that cover the contacts between lamp and leads, when used in rooms where there are explosive or inflammable substances.

Standard Measures of Intensity.—To estimate the value of the lamps of an electric installation we must know their light intensity, but unfortunately no absolute unit has been as yet agreed upon. In France, for instance, as was pointed out on page 224, the flame of a Carcel burner is taken for the standard, this flame being 40 millimetres in height, obtained by a wick of 30 millimetres diameter, consuming 42 grammes of purified rape oil per hour. In England lamps are measured by spermaceti candles giving a flame 45 millimetres in height, and requiring 7·77 grammes per hour. In Germany paraffin candles are used, 20 millimetres in diameter, producing a flame 50 millimetres in height. The wick of this candle consists of 24 cotton threads, and weighs dry 0·668 gramme per metre. The long flame is, however, unsteady, and this standard is therefore now disregarded, and most cities of Germany, in their contracts with gas companies, adopt special standards. The Munich stearine candle consumes 10·2 to 10·6 grammes of stearin per hour, producing a flame of 52 millimetres. The candle is made from stearine, which contains from 76 to 76·6 per cent. of carbon. The following table shows the numerical relation between these units:

Carcel burner.	Spermaceti candle.	German Union candle.	Munich candle.
1·0	7·435	7·607	6·743
0·134	1·0	1·023	0·907
0·132	0·977	1·0	0·887
0·148	1·102	1·128	1·0

As these units, owing to their complicated composition, etc., can give but approximate results, new light units have been proposed by Violle, Schwendler, Draper, and others. The light unit by Hefner-Alteneck consists of a free flame, which rises from the cross section of a massive wick saturated with amylacetate, which fills a circular German silver tube, 8 millimetres inner, and 8·2 millimetres outer diameter, by 25 millimetres height; the height of the flame from the wire tube measures 40 millimetres.

It has been pointed out on page 223 that, as regards England, a sperm candle, one of six to the pound, consuming 120 grains of spermaceti an hour, is the unit of light named in all Acts of Parliament which prescribe the quality of coal gas to be supplied by gas companies. There is, however, a considerable variation in the amount of light given by different standard candles, and even by the same candles at different times. In 1879 the Board of Trade appointed a

committee to inquire into and report to them upon the relative merits for measuring the light given by coal gas of the standard candle and of some other standards which had been proposed. The report of this committee, presented in August, 1881, states that: "Not only do sperm candles, as at present manufactured in accordance with the Parliamentary definition, exhibit intrinsic differences which unfit them for use as a standard, but the method of using them permits of variations which introduce serious errors into this mode of testing the illuminating power of coal gas. For these reasons we consider the sperm candle, both from the uncertainty attaching to the material and manner of manufacture, and from its liability to variations in mode of use, to be so untrustworthy as a standard of light as to render the introduction of a more trustworthy standard of essential importance." The committee conclude by recommending that for the determination of the illuminating power of coal gas the use of the sperm candle should be discontinued, but no other standard has yet been legalised. The "pentane" burner, devised by A. Vernon Harcourt, has been largely used in the experiments on lighthouse illumination "Pentane" is a gas of definite composition,* burning with a uniform but somewhat feeble luminosity, and its flame is used as the standard. The gas is burned in a narrow, slender jet, the absolute luminosity of which increases as the height of the flame is increased. The light to be tested and the light of the pentane jet are cast upon a photometer, and the jet is raised or lowered until the necessary equality of illumination is obtained. By the side of the jet there is a vertical bar, upon which a horizontal wire of platinum slides up and down. When the test is otherwise complete, the horizontal wire is brought down until it touches the tip of the pentane flame, the height of which can thus be precisely measured. The precise value of each millimetre of the pentane flame has been determined by an exhaustive series of experiments, with the result that the determination of its height allows the observer at once to read off the luminosity of the flame under examination from previously-prepared tables. When precautions are taken to preserve the pentane flame from being affected by currents of air, it is an unquestionable improvement upon the candle; and its adoption, if legalised, would go far towards the removal of some of the remarkable discrepancies which may be found in the statements of rival companies with regard to the advantages of their respective fuels or methods of consuming them.

Modes of Determining Light Intensity.—To determine the light intensity of any electric lamp, that is, to compare it with a normal flame, the light of the normal candle and the light to be measured are both allowed to fall upon adjacent portions of the same surface or of similar surfaces, these being usually of paper rendered translucent by oiling; and the light which renders the surface more luminous is removed to a greater distance, until perfect equality is obtained. The light received upon a given area from a given source diminishes as the square of the distance between them; and hence the squares

* Pentane is a paraffin containing 5 atoms of C to 12 of H.

of the respective distances, when the illumination from the two sources is alike, furnish a measure of the relative value. If the light of a standard candle at one foot from the testing service is exactly balanced by the light from a given lamp at four feet, the values of the two are as the respective squares of their distances, or, in the case supposed, as sixteen to one. The lamp would be said to be of sixteen-candle power.

Foucault's photometer is constructed on this principle. Fig. 518 represents a photometer constructed by Bunsen. On a frame A B, consisting of white paper, the spot *m* is made transparent by means of stearin or paraffin. Sources of light are placed at both sides; when the light to the left of the screen is stronger than that to the right, the stearin spot will appear lighter than the surface of the paper surrounding it. When the two sources of light are of the same intensity, the surrounding paper and the stearin spot appear equally light. In order that both sides of the paper may be seen at once, it is placed between the mirrors M N and M′ N′, so as to bisect the angle between them.

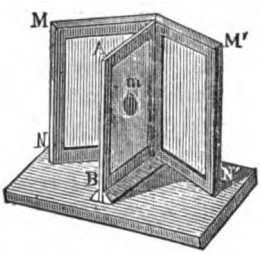


Fig. 518.—Bunsen's Photometer.

Edison's Apparatus.—The form Edison gave to this apparatus is shown in Fig. 519. The screen with its two mirrors moves on wheels between the normal candle and lamp to be compared, which are at opposite ends. The whole apparatus is enclosed in a blackened box to prevent light from entering.

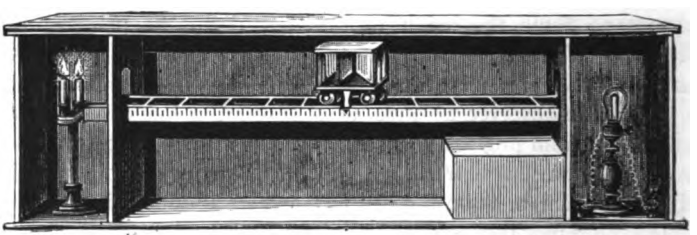


Fig. 519.—Edison Form of Bunsen Photometer.

To measure the intensity of a glow lamp in this or a similar way is not a matter of difficulty; it is, however, different when the light of arc lamps is to be compared. The points that constitute the difficulty are the immense difference between the intensities of the unit of light and the arc lamp; the irregular radiation of the light of an arc lamp fed by continuous currents, and the various tints of the lights to be compared. Instead of using the unit of light, it may be multiplied so as to give some intermediate measure. Even for comparing lamps with small intensities, either some intermediate light, such as a petroleum lamp, is taken, or else the arc light is allowed to pass through a concave lens for the purpose of weakening it.

L. Pfaundler suggests a simple means for mechanically weakening the intensity, viz. that of allowing a disc (shown in Fig. 520) to rotate between the source of light and Bunsen's stearine spot screen. The reduction of the in-

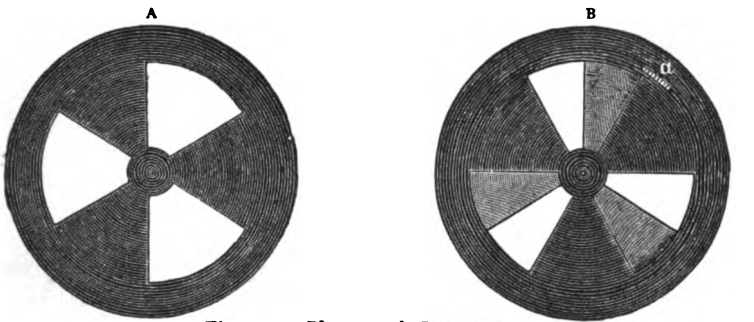


Fig. 520.—Photometric Light Discs.

tensity will be the greater the smaller the total service of the sectors opened. In order to make one disc do for measuring different intensities, H. Hammerl makes use of a double disc (shown in Fig. 520 B), consisting of two circular

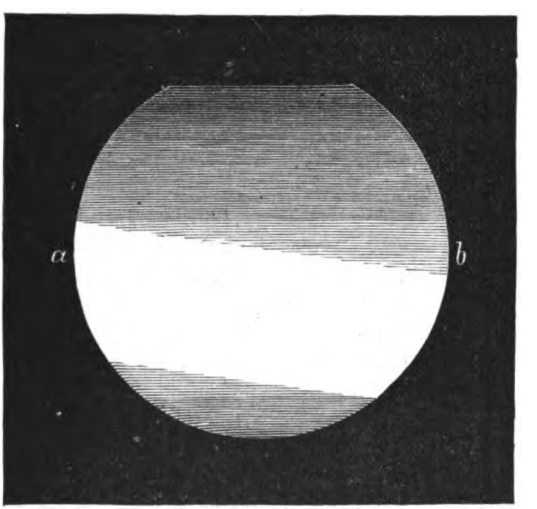


Fig. 521.—Globe lit by Continuous Current.

discs having equal segments cut out, which move about an axis at their centres, so that these segments may be made larger or smaller, as required; the sum of the angles formed by the open segments of the two discs is read off a scale at *a*.

Arc lamps fed by alternating currents have their carbons equally pointed, and the light they give out is therefore uniform in all directions. If, however, continuous currents are used, the positive carbon becomes blunt, or even

hollowed out, whilst the negative carbon becomes pointed; the consequence is that the greater portion of the light comes from the positive carbon, and no longer runs horizontally, but makes a certain angle with the horizontal plane. (According to Fontaine, an angle of from 50° to 60°; according to Hefner von Alteneck, 37°.) A glass globe surrounding a lamp fed by continuous currents is shown in Fig. 521.

A view of the room for photometric observations at the Exhibition for Electricity, Munich, 1858, is given in Fig. 523. In this room there were two photometer lines or scales, A B and B C (Fig. 522), measuring 6 to 12 metres. At A the normal candle or the argand burner I could be placed. At II a burner, the opening of which was one millimetre in diameter. At B a Siemens gas burner or a glow lamp was placed, and at C the arc lamp to be examined. At *a* and *b* stood the movable Bunsen's paper screens; G G indicate apparatus for measuring gas, between which the regulator R was placed. The spermaceti candle was taken as the light unit, but instead of using the candle directly, a series of steps or grades of intensity were arranged between it and the arc lamp. As the first of these, the gas burner II was employed, and before each measurement compared with the candle by means of the photometer *a*; the burner was supplied with gas by a gas-meter of one-candle power. The gas-burner II was then compared with the argand burner at A, supplied with gas by a 16-candle power gas-meter. A was then compared with a Siemens burner at B, which received gas from a gas-meter of 30-candle power. The Siemens burner was then taken as a measure for the arc lamp at C. The unequal radiation was compensated for by measuring the intensity in a horizontal direction under an angle of from 30° to 60°; besides this, measurements were made under angles specially mentioned by manufacturers. For this purpose a mirror S was used, which was movable about a horizontal axis *c*, whilst the lamp L was burning at a constant height.

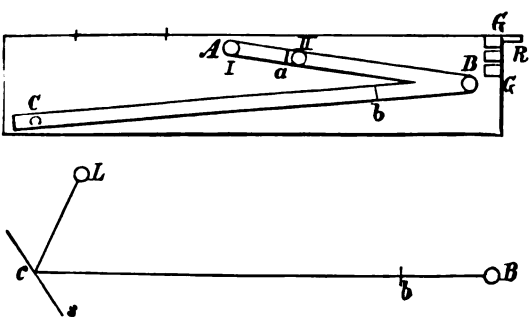


Fig. 522.—Photometric Apparatus at Munich.

Electric as Compared with Gas and other Light.—Before deciding to adopt the electric light for a particular purpose, it is not only necessary to consider the technical perfection of the apparatus for producing it, but also whether electric light would be advantageous as regards its properties. The electric light not only surpasses gas, but all other artificial sources of light in its intensity, although some declare that it has a bluish tint, and rather resembles the light of the moon than that of the sun. Experiments made with sun, gas,

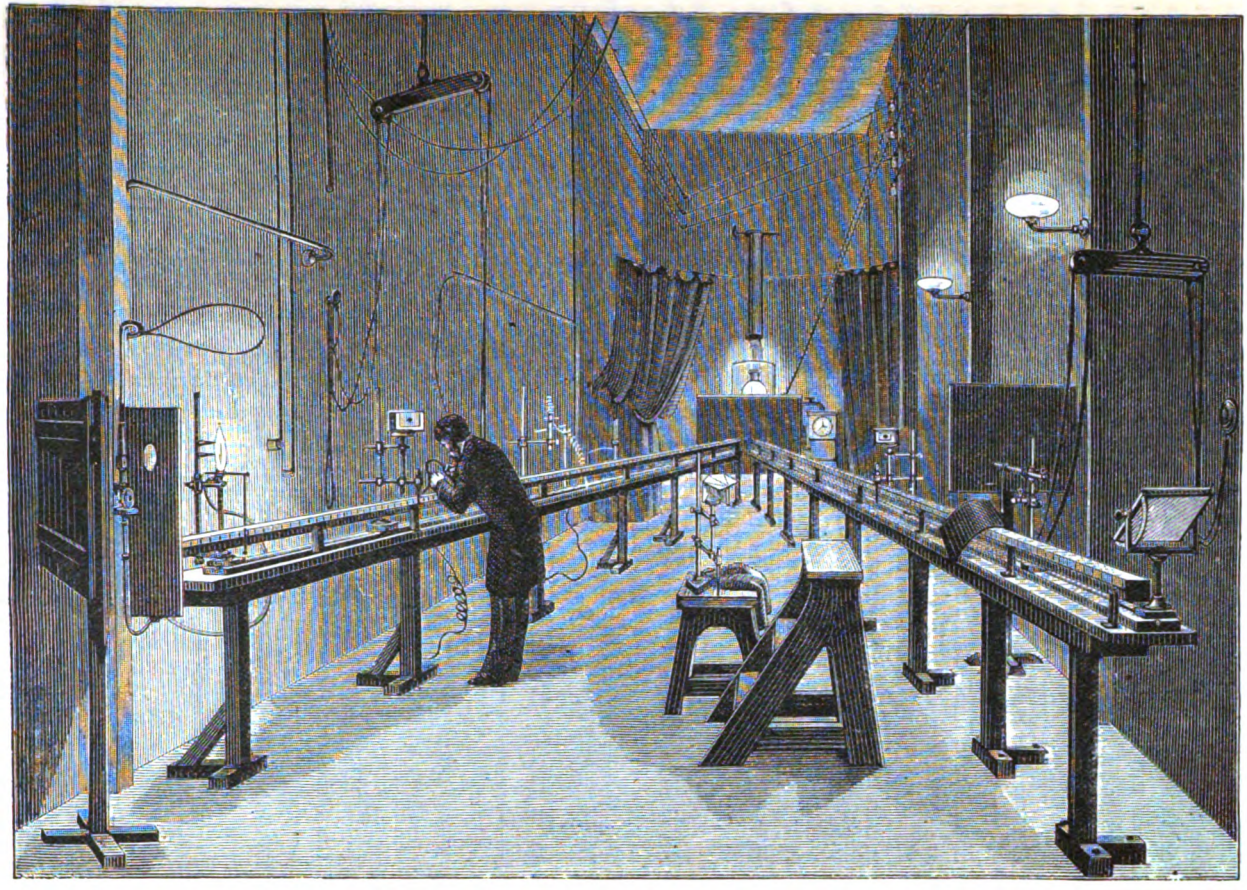


Fig. 523.—Photometric Room at the Munich Exhibition.

and electric light have shown that gas-light is richer in red rays than either of the others, but the electric light is richer in violet rays than either the gas-light or sun-light. It has been further found that sun-light is more luminous in its green and blue constituents than the electric light, but that the latter may surpass the former in red and violet. To show that the electric light compared with sun-light appears yellowish or reddish, we need only illuminate a portion of a surface by sun-light and a portion by the electric light. The colour of the electric light is therefore preferable to that of gas-light, and it is only because we are at present accustomed to see everything in a reddish light that we find the electric light cold and unnatural. When the two colours, green and blue, are seen by gas-light it is often difficult to distinguish the one from the other, although by electric light these colours are easily distinguished. Sometimes it is of the greatest importance that we should be able to see objects in their natural colours, as, for instance, in weaving, spinning, and printing establishments, etc.; here the advantages of the electric light are obvious. Although the electric light compared with sun-light appears reddish, the large proportion of violet rays that it contains makes it available for photographical purposes, where gas-light would be perfectly useless.

The advantages of electric light from a hygienic point of view cannot be disputed. Gas and all other artificial lights consume great quantities of the oxygen in the air, and make it injurious to health by the formation of CO_2. The results of experiments made by F. Fischer with different sources of light to determine the consumption of oxygen, the heat produced, and the formation of carbon dioxide by each, are given in the following table:

Quantity of O necessary for the Production of a Light of 100-Candle Power per Hour.		Generated.		
Source of Light.	Quantity.	Water in Kilogram.	CO^2 at 0°.	Heat in Calories.
Electric arc light	0·09 to 0·25 p	Not determined		59 to 158
,, glow light	0·46 to 0·85 p	—	—	290 to 536
Gas, Siemens' regenerative burner... ...	0·35 to 0·56 ohm.	—	—*	1,500
,, argand burner	0·8 ohm. (−2)	0·86	0·46	4,860
,, burner with two openings	2 ohm. (−8)	2·14	1·14	12,150
Mineral oil, large round wick	0·28 kg.	0·37	0·44	3,360
,, small flat wick	0·60 ,,	0·80	0·95	7,200
Rape oil cover lamp	0·43 ,,	0·52	0·61	4,200
,, lamp for studying	0·70 ,,	0·85	1·00	6,800
Wax	0·77 ,,	0·88	1·18	7,960
Stearine	0·92 ,,	0·04	1·30	8,940
Tallow	1·00 ,,	1·05	1·45	9,700

M. V. Pettenköfer's results, comparing the CO_2 produced by gas with that produced by glow lamps, at the theatre at Munich, are given in the following table (the readings were taken in an empty house):—

* The gases produced during combustion are conducted away in the Siemens regenerative burner.

	Gas.		Electric Light.
	After 30 Minutes.	After 60 Minutes.	After 60 Minutes.
Pit	0·5	0·6	0·5
I. balcony	1·1	1·0	0·5
III. balcony	1·4	2·0	0·6

At an international hygienic meeting at Turin, Layet pointed out that gas not only affects animal life, but greatly increases the danger of fire. The electric light, however, has drawbacks which gas has not. Gas is conveyed from the place of production to the places where it is consumed easily and without loss; but electric light cannot be divided without loss of energy; the greater the partition the greater the loss, no matter how carefully the leads are carried out. At present gas-light has this advantage over electric light, that it is produced at large centres and in large quantities. The loss of energy in dividing the electric light would considerably diminish if large centres were established for its production. It has been said that by using electric light the danger of fire is considerably lessened; but this is only true when the arrangements are without fault. As long as the currents pass through proper and sufficiently insulated conductors, there is no danger whatever; but fire may be caused when a short circuit is produced, and this may happen when branch wires become connected with each other by means of metallic dust, thin wires, wet or saturated wood, etc. etc. Such imperfect conductors may become heated, and finally burst out into flame. In arc lamps, through an undue increase of the current, it may happen that the arc does not form between the carbons, but between the metallic portions, which it then melts. All these, however, are exceptional cases. The electric light may further become dangerous through its physiological effects; cases have occurred where persons have been killed by coming in contact with conducting wires; but this can only happen when currents of high potential are used, and for this reason they ought to be avoided, or, where this is not possible, perfect insulation should be insisted upon. We may sum up the advantages and disadvantages of electric light and gas-light as follows: Where powerful lights of great intensity are required, electric light would be preferable to gas-light; but if the lighting consists of a great many small lights, gas is preferable to the electric light, because it is easily divided without loss of energy. Objects are seen by electric light in their natural tints, whilst by gas-light some colours cannot be distinguished at all, and others appear different. For chemical effects, gas-light is altogether impracticable. The electric light hardly increases the temperature in enclosed spaces, and products of decomposition injurious to health and inanimate objects are not formed; whereas gas raises the temperature considerably, and also causes the formation of carbon dioxide, compounds

of sulphur, etc., which are injurious to health as well as to inanimate objects. Although the comparison of cost between electric light and gas-light is of great importance, little can be said about it at present; plants on a large scale will produce electric light cheaper than plants on a small scale; moreover, the cost greatly depends upon whether the dynamo machines are driven by steam, gas, water motors, etc., and whether glow lamps or arc lamps are used, with continuous or alternating currents. The electric light could not be the cheaper if fewer than fifteen to twenty glow lamps were required; but if twenty to twenty-five were required, the electric light would, in some cases, prove cheaper than gas. Glow lamps possess the advantages of gas without its disadvantages, and it is really glow lamps that will have to compete with gas, for where large powerful lights are required there can be no doubt as to the superiority of electric light over gas-light.

The adoption of the electric light would by no means do away with gas; this would, on the other hand, probably become more important than ever, although its form of utilisation would possibly become altered. Using gas for heating purposes is a rational utilisation of the coal, for during combustion of the gas the production of heat is far in excess of the production of light, which is proved by the heating of the air in closed spaces, and still further by the following statement:—Large gas engines produce one horse-power by the consumption of a cubic metre of gas per hour. With such an engine, by using the electric arc light, a light of 1,700-candle power can be obtained; but if this quantity of gas is consumed by ordinary gas burners, only seven flames of 10-candle power each are obtained, *i.e.* a light of 70-candle power. It is, therefore, possible that the electric light may gradually take the place of gas, although gas will not become useless. It might be used on a still larger scale for heating purposes, especially as the production of heat-gas is cheaper than that of light-gas. This would, from a sanitary point of view, greatly improve the buildings of large towns, and would cause their atmosphere to be purer and more healthy by freeing it from smoke.

APPLICATIONS OF THE ELECTRIC LIGHT.

It seems far easier to enumerate the few cases for which the electric light is not available than to make a complete list of those where it can be used; we shall, therefore, only give a few of the most important applications.

The Lighting of Buildings by Electricity.—The lighting of public buildings by electricity, if proper precautions be taken as regards conduction and insulation, would diminish the chances of fire. We have statistics to show that within the last twenty-five years about 290 theatres have been burned down, 28 per cent. of which were opened only five years, 15 per cent. six to ten years, 18 per cent. eleven to twenty years, and 20 per cent. twenty-one to thirty years. By these accidents 10,000 people have been thrown out of employment, and the damage is estimated to have amounted to £7,500,000.

The first large theatre lighted by electric light was the Savoy Theatre in London; soon followed others in Brünn, Havana, Boston, Munich, Mailand, Manchester, and Buda-Pesth. The plant for the theatre at Brünn has been furnished jointly by the Société Électrique Edison, Paris, and the company of Brünckner, Ross, and Consorten, Vienna. The theatre, which covers an area of about 2,100 square metres, accommodates 1,200 persons. The building for the machines is 300 metres distant from the main building. Fig. 524 represents the

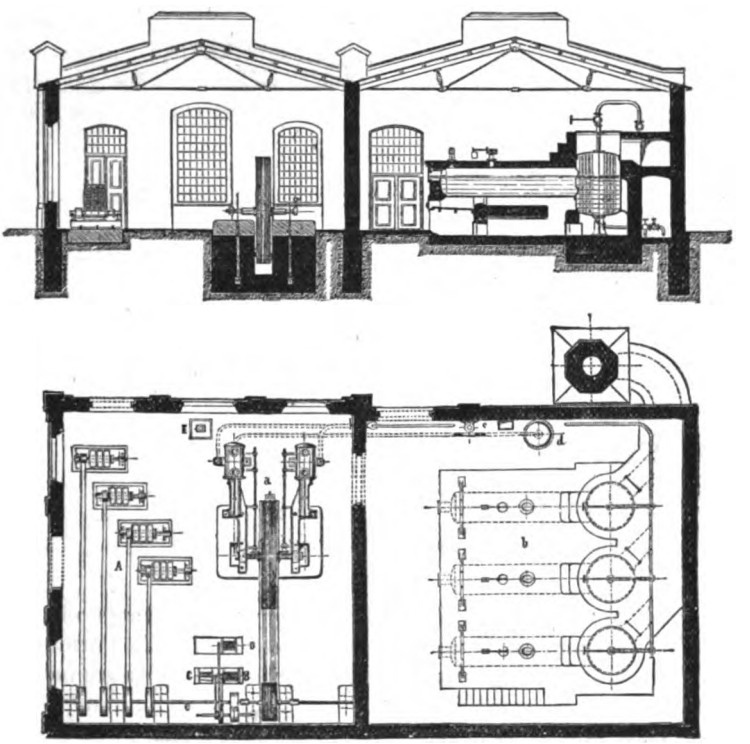


Fig 524.—Installation for the Theatre at Brünn.

arrangement of the machinery. In the boiler room, three cylindrical boilers *b* are bricked in; these boilers have together a heating surface of 168 square metres. Only two of them are in use at the same time; the third is kept as a reserve in case of accidents. The steam engine *a* is a 110 horse-power high-pressure machine (by Collmann), making 105 revolutions per minute. The fly-wheel, of 4 metres diameter, transmits the energy by means of seven hempen ropes, 40 millimetres long, to a shaft *e*; ordinarily the engine is not worked to its full power, so that in case of repair being necessary one-half of the engine can do the whole work. The driving-wheel has a diameter

of 1·1 metre, and makes 300 revolutions per minute, and cotton belts transmit the motion to four Edison and three Gramme machines. The four Edison machines A make 900 revolutions per minute, and each is capable of supplying a current for 250 Edison lamps of 16-candle power; of these 1,000 lamps, never more than 900 are in use at the same time, so that in case one machine should become damaged the remaining three can be worked to their full power. Of the Gramme machines, B is intended for the five arc lamps, C for the production of stage effects, and D for working a ventilator. E is the regulator, by means of which greater or lesser resistances in German silver wire may be inserted in the circuit of the electro-magnets. The currents from the machines are conducted to the required points by cables. Fig. 525 represents the arrangement for the branching off of the current conveyed by the cable;

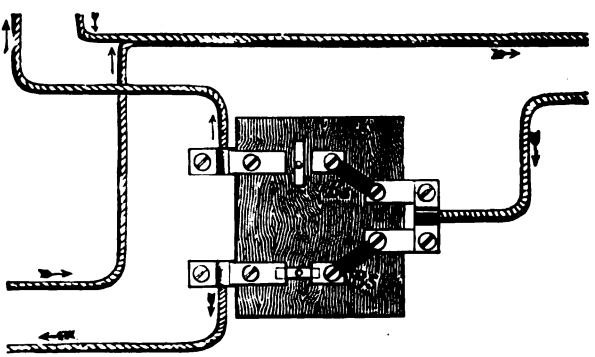


Fig. 525.—Arrangement for Distribution of the Current.

the arrows without tails indicate the leads belonging to the lamps which require no regulation, *i.e.* lamps on the staircases, halls, etc. The tailed arrows indicate the leads of the parts of the system requiring regulation, such as are on the stage, etc. At B *s* safety wires, consisting of lead, are arranged within the building; the copper wires are covered with fireproof cotton, and safety wires are inserted between every six to ten lamps.

Apparatus for Stage Effects.—The most difficult portion of the lighting of theatres is the stage, and a very complicated apparatus is required for its regulation. The regulators used in the theatres at Munich and Stuttgart are copies of the model that was exhibited during the Exhibition at Munich. Fig. 526 shows the entire arrangement, and Fig. 527 represents a single element. The apparatus consists of a series of levers M, which move over a number of contacts arranged in a circle. The several circuits are connected on one side with the lever M; on the other side with the contacts *x y*. When the lever is in contact with *x*, no resistance is inserted, and the lamps burn with their full power. In the position of the lever shown in the diagram,

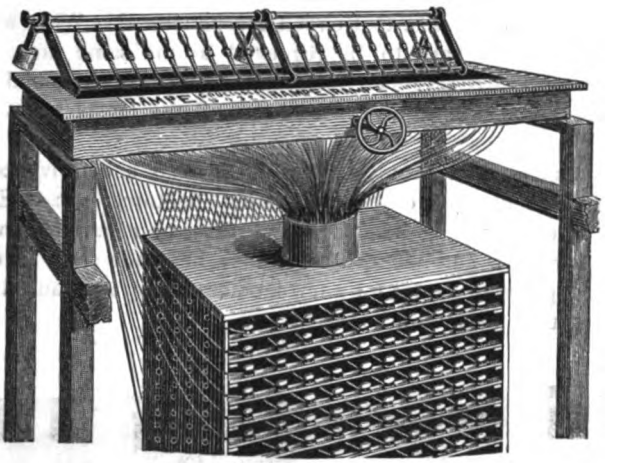


Fig. 526.—Stage-Light Regulator.

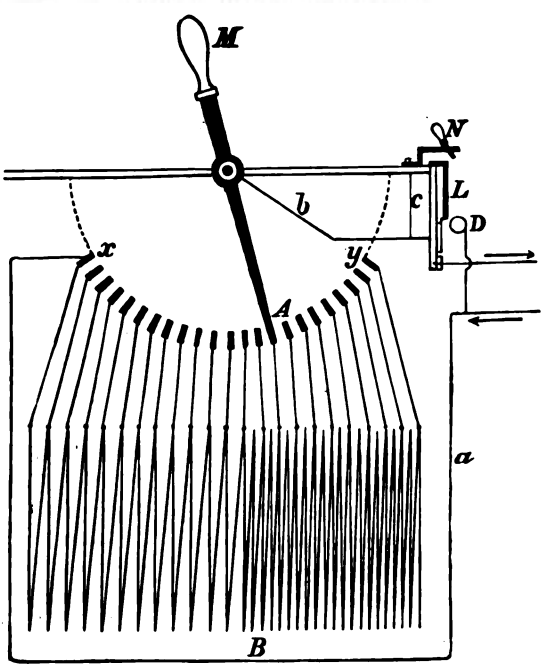


Fig. 527.—Stage-Light Regulator.

all the resistances between *x* and A B are inserted. The current coming from *a* cannot flow over B, through the lever M to reach *b*, without first passing through the resistance coils A B. By moving M the resistance can be altered at pleasure,

i.e. the intensity of the lamps of that circuit can be altered. When all or several of the groups of lamps have to be regulated at the same time, the several handles of their respective levers are raised by means of a horizontal frame, with which they are connected, and which moves all the levers when a wheel is turned (*see* Fig. 526.)

The apparatus used in Munich and Stuttgart has a contrivance by means of which a sudden flash is effected, imitating lightning, etc. Every group of lamps has a corresponding handle (N, Fig. 527), by means of which contact between the spring L and the contact *c* may be made; by taking out the resistance of the group of lamps for a few moments, they are caused to glow up for an instant at their maximum intensity.

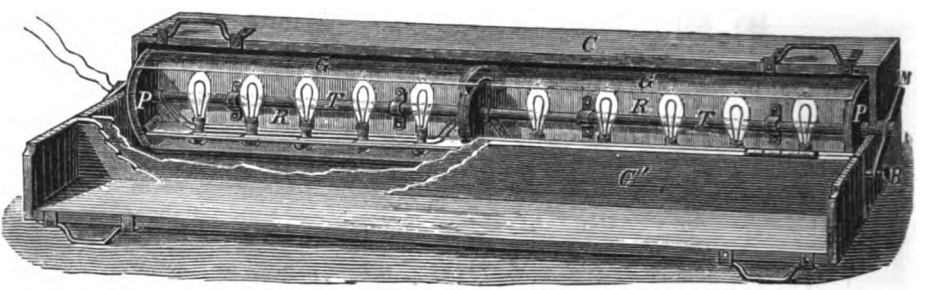


Fig. 528.—Arrangement for Coloured Stage Effect at Munich.

Care has to be taken when a number of lamps are extinguished at the same time, that the remaining lamps may not have too powerful a current. By Edison's system the attendant is informed of this by a signal, and he, by the help of a rheostat (E, Fig. 524), inserts resistance in the current of the electro-magnet. At Stuttgart the weakening of the current is made known to the attendant from the stage by a green light; the increase of current by a red light. In Munich coloured light is produced by placing red or blue gelatine screens before the lamps of the several groups. Fig. 528 represents an arrangement for one group. The iron tube T carries the reflector R, having the glow lamps on its lower horizontal portion. The tube T rests with its ends upon the sides of a wooden box, the lid C C′ of which can be thrown back on either side. By means of the handle M the lamps and reflector can be turned as required. The circular discs P P are intended to hold the gelatine cylinder G G open for one-third of their circumference. Coloured light is obtained by moving G G by means of wire ropes and pulleys. Brandt, of Berlin, has the groups of lamps in three separate circuits: one for white, the second for green, and the third for red lamps. This arrangement facilitates the regulation from a central point, but the cost is considerably increased, as three times the number of lamps are required for the stage.

The National Theatre, Buda-Pesth, has an apparatus made by the firm of Ganz and Co. Here four machines, for producing alternating currents, supply the necessary current; the colour effects are produced by three different groups of lamps, each group having a separate circuit; one group of these lamps remains uncovered, the second group is covered by red, and the third group by green glass plates (Fig. 529). By using the alternating current machines of twelve circuits each (altogether forty-eight circuits), the light regulation is effected without the insertion of resistances. Each group of lamps is made active by means of the corresponding number of the forty-eight circuits, each of which forms a separate source of electricity. The lamps of the auditorium have, for instance, nine of such sources of current, and can, therefore, have nine different degrees of intensity. The footlights receive twenty-one currents, which can be collected and distributed by a commutator, so that each group of ten lamps can be regulated separately, or all the groups can be manipulated together.

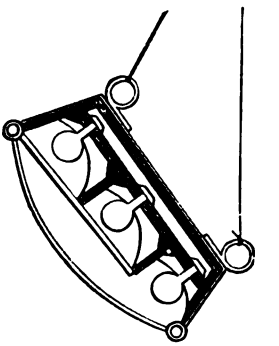


Fig 529.—Colour Apparatus.

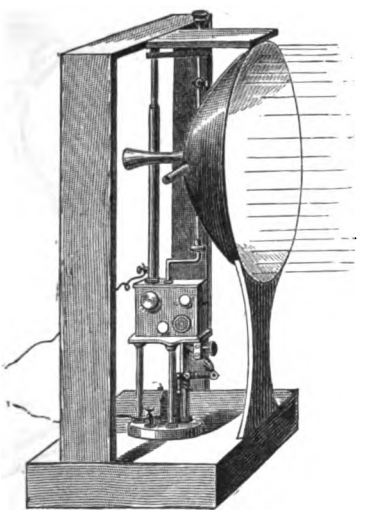


Fig. 530.—Sunrise Apparatus.

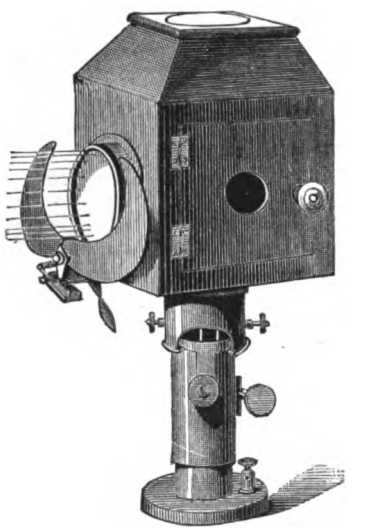


Fig. 531.—Apparatus for Illuminating Actors.

Apparatus for imitating natural phenomena, and for throwing the light upon individuals, etc., is very often used. Fig. 530 represents the apparatus which Duboscq devised for the representation of sunrise in the opera "Der Prophet;" it consists of a Foucault-Duboscq regulator fitted with a parabolical

concave mirror. The parallel pencils of rays are allowed to fall upon a transparent screen, producing a circular disc of intense brilliancy; this disc can be made to move by moving the apparatus. The ordinary apparatus used

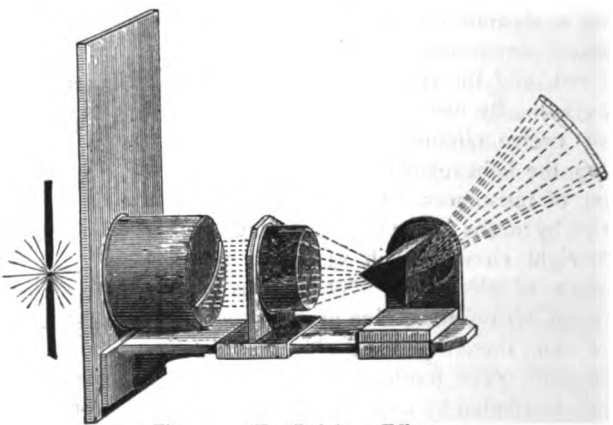


Fig. 532.—For Rainbow Effects.

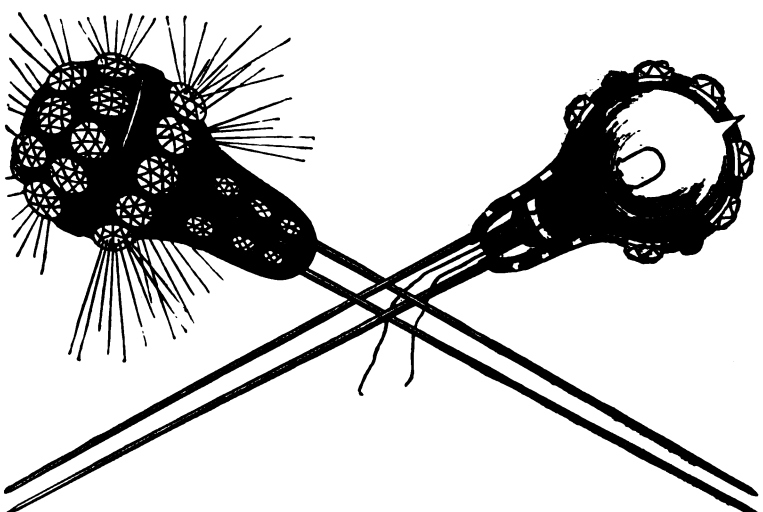


Fig. 533.—Trouvé's Electric Jewels.

for throwing light upon the actors is shown in Fig. 531. For the imitation of rainbows, the apparatus in Fig. 532 is used; the lens between slit and prism serves the purpose of concentrating the rays of light, and also of increasing the bend of the rainbow.

Electric Jewels.—Trouvé makes use of glow lamps, the carbons of which have a very small resistance, for his jewels. Fig. 533 represents a hair-pin

In case of damage the lamp is easily replaced by a new one. The wires lead to a battery consisting of zinc and carbon rods immersed in potassium bichromate; this battery is enclosed in a box of gutta-percha. These batteries with cases only weigh 300 grammes, and supply to lamps a current of 2 to 3 volts for about thirty minutes. The battery box is prismatically shaped; the shortest edges are three and a half centimetres, the longest five to six centimetres long. In

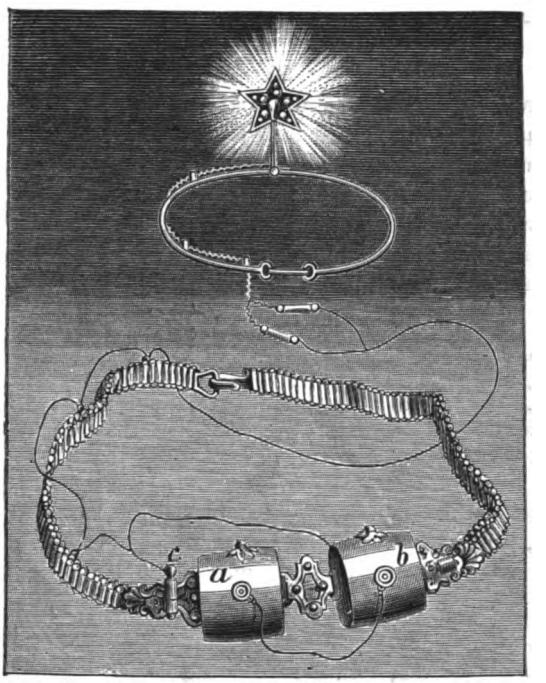


Fig. 534.—Diadem Apparatus.

the ballet of the new opera, "La Farandole," faint glow lights resembling will-o'-the-wisps (*ignis fatuus*) play on the heads of the dancers. These are produced by the apparatus shown in Fig. 534. The dancer wears on her head a metal ring holding a glow lamp and a star-shaped metallic mirror, upon which pieces of green glass are fastened. The two elements which supply the lamp with the current are contained in the vessels *a* and *b*, fastened to a belt. At *c* is a smart current-breaker which enables the dancer to put the light in or out. The battery consists of a chloride of silver element arranged as in Scrivanow's battery (*see* p. 405).

Electric Light for Printing-Rooms.—The unhealthy effects of gas are especially felt by workmen in establishments where it is necessary to work very

near to the light. The printing office of Messrs. Jaenecke Brothers, in Hanover, has been recently fitted with an electric lighting system, executed by Uppenborn and Gackenholz. The plant of machinery consists of three Schuckert flat-ring compound machines; one of these machines, placed in the basement, is driven by an Otto gas engine, and is intended as a reserve. All the machines are joined parallel to each other, and in order to avoid reversion of the poles of their electros, their negative brushes are connected by means of short wires. The current of each machine may be regulated by means of resistances inserted in the inducing circuit. The current coming from the machine has first to pass through a contact-breaker of four contacts, consisting of an ebonite cylinder, with two metal contacts and two brushes for each contact. The spark is by this arrangement divided into four sparks, and the contact-breaker is prevented from wearing out too quickly. The currents of the machine then pass into two main conductors, from which leads spread to the different rooms. The electric apparatus extends over the machine rooms, two composing-rooms, and a lithographic room, having 125 Edison lamps of eight candles, eight lamps of ten candles, and four lamps of sixteen candles, distributed as follows:

	Lamps of 8 candles.	Lamps of 10 candles.	Lamps of 16 candles.
Machine room	16	6	—
No. 1 composing-room ...	52	—	2
No. 2 „ „ ...	50	1	2
Lithographic room ...	6	1	—
Steam-engine room ...	1	—	—

In an arrangement like this, it is necessary that the lamps should be simple, easily managed, and cheap. Three lamps of eight-candle power give light to the central passage of the printing-room. These lamps are simply screwed to gas tubes which hang from the ceiling, and the wires are conducted inside the gas tubes. This manner of fastening the lamps could not be adopted for the lamps intended to give light to the men working at the printing machines, as the lamps employed must be movable. They are therefore constructed as follows: To the lower end of the vertical gas tube a rod, bent into the

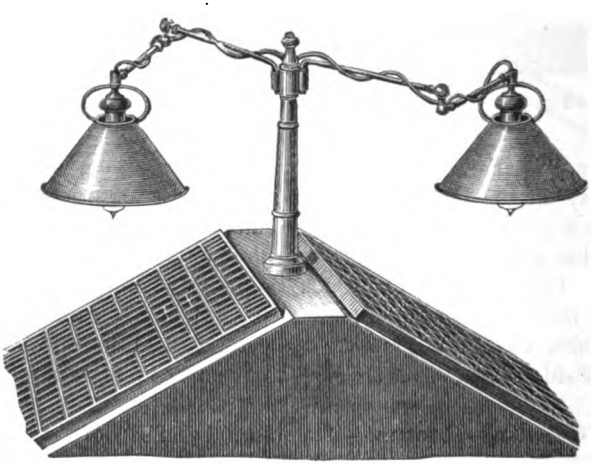


Fig. 535.—Lamps for a Printer's Composing-room.

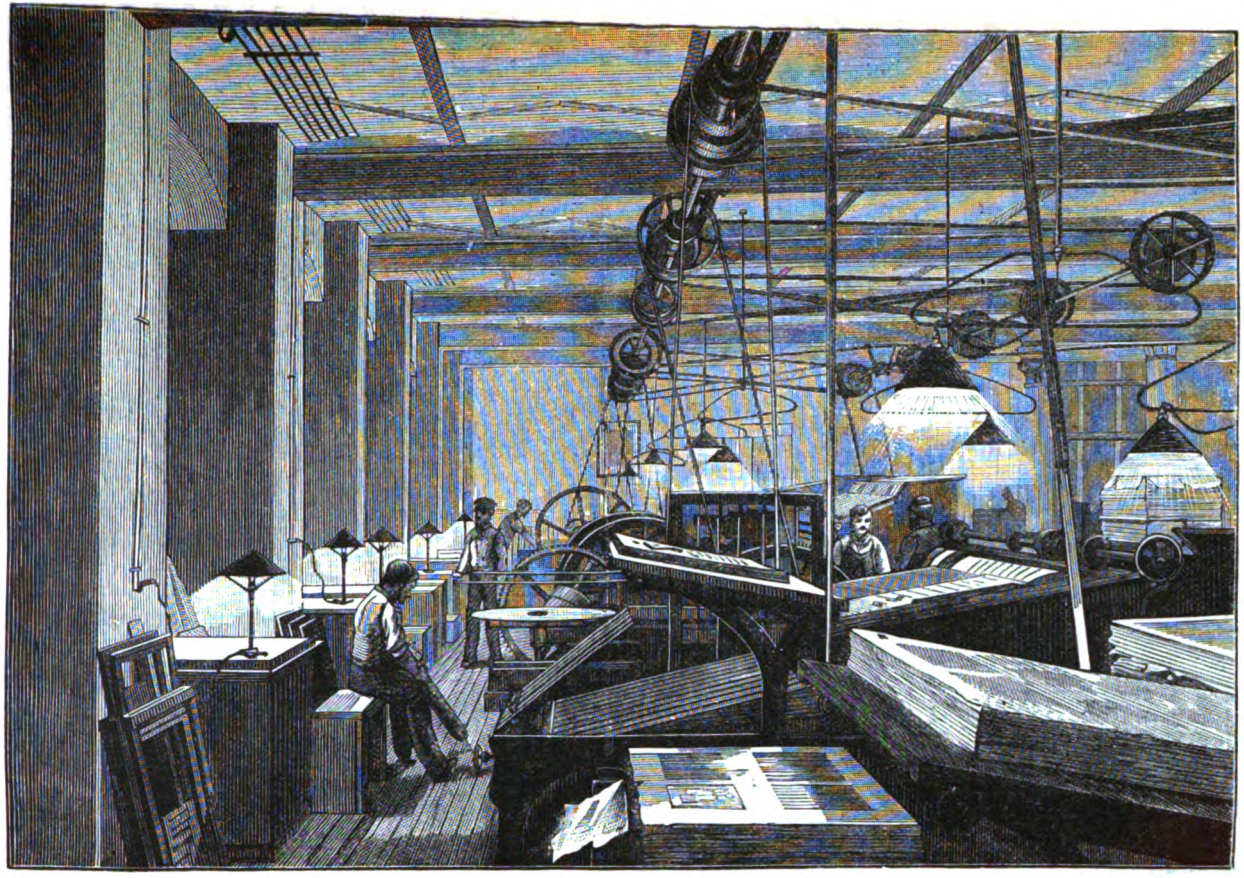


Fig. 536.—Electric Light in Messrs. Jaenecke's Printing Office, Hanover.

form of a trapezium, is fastened; in this the lamp, with its reflector, is hung. Fig 536 gives a general view of the printing-room. The trapezium moves in a semi-circle about the gas tube, and the lamp itself along the base of the trapezium. The lamp can thereby assume any position within a certain radius. It is connected by means of a flexible cable with the conducting iron, which comes out of the gas tube. This room has also a set of hand-lamps, which are supplied with currents from leads which are found at every window-pillar in the room, and are connected with Edison contact boxes. Each of the plugs has a leaden wire attached to guard against currents which are too strong. The lamps used in the composing-rooms are shown in Fig. 535.

Electric Light Companies in New York.—The largest *central station for electric lighting* is the one in New York managed by Edison. The central station at Mailand is next. At present a central station is about to be instituted at Boston, the execution of which has been undertaken by the Merchants' Electric Light-Power Company. Similar stations are to be erected in Paris and Berlin. The central station of Mailand was instituted by a committee consisting of the members of the most important banking establishments of that city; Messrs. Giuseppe, Colombo, and Guzzi were consulted as experts. The reports brought back by these gentlemen on their return from their journeys to Paris and England caused the committee to vote the necessary means for the erection of a central trial station on a large scale; but the company is not to be formed before this station has sufficiently proved its efficiency. The central station is close to the largest theatres, clubs, shops, etc. The building covers an area of 624 square metres, and consists of three storeys, of which the ground floor is 3 metres underground. Here, for the present, four Edison steam dynamos are placed, each of which is capable of supplying 1,000 to 1,200 Edison lamps of sixteen-candle power, with currents requiring from 120 to 140 horse-power. The armatures have a diameter of 0·75 metres, and make 350 revolutions per minute. The bearings of white metal in which the steel axis runs, are kept cool by means of water. The cooling of the armatures is brought about by air currents. Two light machines are driven by Porter Allen and two by Armington and Sims engines. The shafts of the steam and light engines are everywhere coupled directly, and not by bands. All the steam dynamos are placed parallel to each other, as shown in Fig. 537. The steam for the engines is supplied by boilers by Babcock and Wilcox, of which there are five, placed under the machine room. Each of these boilers can supply steam for two dynamos. The difference of potential of the currents is kept constant at about 110 or 120 volts. A current of 1,200 amperes is obtained when all the four machines are in action. The principal consumer is the Théâtre de la Scala, where usually 1,600 lamps are required. When "Don Carlos" was given, 2,062 lamps were required. The leads of this theatre are about 400 metres long, and their contacts are so well calculated that the loss of potential does not exceed eight volts.

Use in Mining and Tunnelling.—Electric lighting has become of

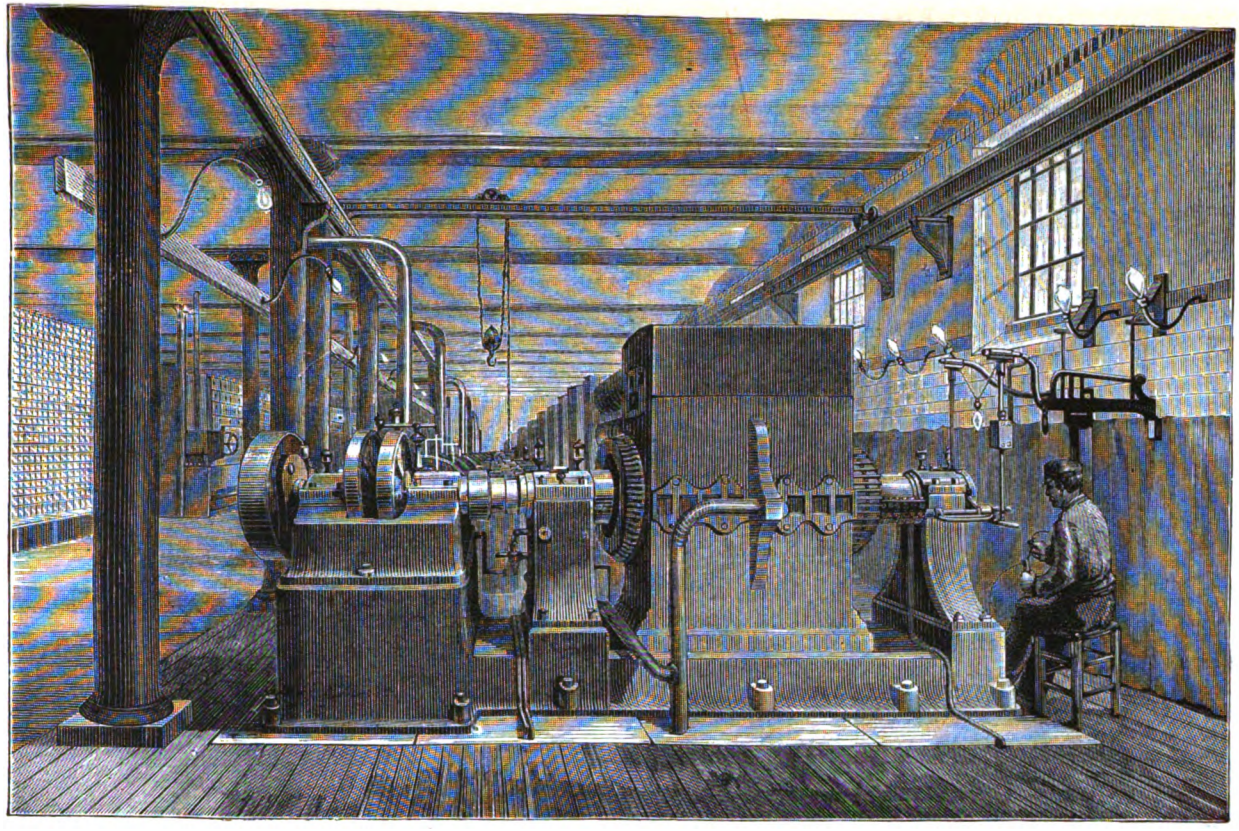


Fig 537.—Central Electric Lighting Station at Mailand, New York.

great importance for tunnel and similar constructions. The boring is usually done by pneumatic machines; but a combined application of electricity for

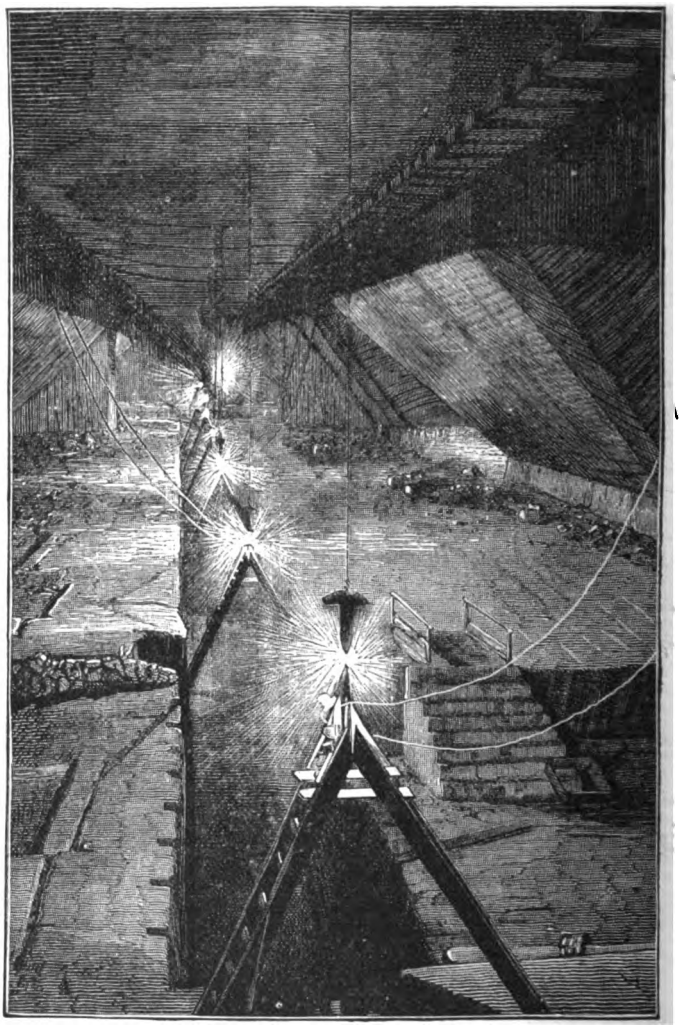


Fig. 538.—Electric Light in the Salt Mines of Maros-Ujvar.

lighting, working the boring machine, ventilating, etc., might prove more advantageous. At the construction of the St. Gothard tunnel the pneumatic machines employed returned only from 4 to 8 per cent. of the energy bestowed upon them. In the Austrian salt mines at Maros-Ujvar (Hungary), which

Fig. 539.—Electric Light at the Copper Mines of Rio Tinto.

cover an area of 24,000 square metres, and employ from 400 to 500 men, experiments, made in 1880, led to the adoption of the electric light, the work being executed by J. Neuhold, agent to Siemens and Halske. A 10 horse-power movable steam engine drives the Siemens light machine as well as the generating machine. The winding machine and the locomotive are supplied with steam from the same source. The total intensity of the fifteen lamps is that of 4,000-candle power. All the lights are required only during the eight working hours; during extraction one-half of the lamps is taken out of circuit, and the locomotive works at a rate of 5 horse-power only. The conducting wires to and from the engine are mostly covered, but in dry portions of the mine uncovered wires, insulated in very much the same way as the wires of telegraph lines, are sometimes used. The leads and lamps are arranged as follows: Two leads leave the light machine; the one with insulated wires is conveyed to the salt pit and conducted to the different chambers, each of which has two lamps resting on salt pyramids; the other, consisting of wire which is not insulated, is conveyed to four lamps, one in each chamber (besides the two connected with the insulated wire), and also to three lamps distributed over the passage of the entering shaft. The lamps are lowered as the depth of the shaft increases; this has happened once in two years. The carbons of the lamps are 20 centimetres long by 0·5 centimetres broad, producing an arc of from 3 to 4 millimetres in length. During the insertion of new carbons, that is, after every four hours, the current is passed through single-branch lamps. The total expense per annum amounts to £625. Compared with the previous expenditure for tallow, oil, etc., it is found that the electric lighting is not much more expensive, although the lighting is better and less injurious to health. Fig. 538 represents a portion of the mine taken from a photograph. As another instance of electric lighting, the copper mines at Rio Tinto, in the province of Huelva, Spain, as shown in Fig. 539, may be given. The hills where these mines are situated have strongly inclined slopes and valleys, or trenches, the widest being about 106 metres across. The lighting arrangements have been executed by the firm of Siemens, London.

The Lighting of Railway Stations.—The electric light has proved of such advantage for railway stations, that already almost all the larger stations have a system of electric lighting. The apparatus of the new central station, Strasburg, opened in August, 1883, is amongst the largest of this kind. The position of the different buildings, lines, etc., may be seen from Fig. 540. The Alsace Electric Company (Ungerer and Schulze) were entrusted with the execution of this undertaking. The firm of Siemens and Halske furnished the machines, lamps, material for leads, etc., for the arc lights. Ungerer and Schulze furnished the material for the glow lamps; the steam engines and boilers were supplied by the Carlsruhe Machine Factory at Carlsruhe. The building containing the machines is divided into two portions; one portion contains the five boilers which supply the different machines with steam, and also the offices for heating purposes. To produce one horse-power the boilers

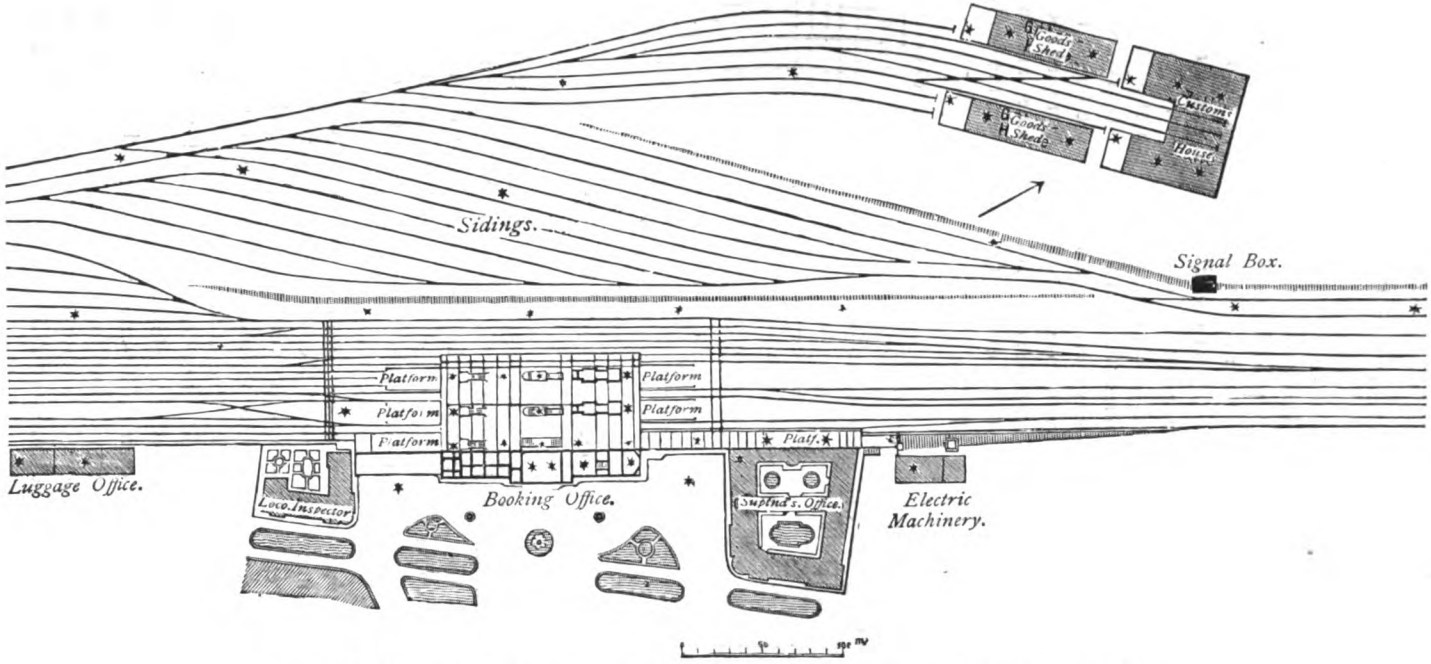


Fig. 540.—Electric Light Installation at the Railway Station, Strasburg. Arc Lights denoted by *.

require 1·7 kilogramme of coals; the time for getting up steam is forty minutes. A pipe from the boiler room leads into the room where the steam and light engines are placed, and from it pipes branch off to the different machines and offices. The machine room is again divided by a passage, on one side of which are placed fourteen continuous current machines, by Siemens, for feeding 60 arc lamps, and on the other side three Edison machines for 250 lamps, of 16 normal candle power each, and another machine for 450 of such lamps. Each side has three compound machines of 45 horse-power, making 150 revolutions per minute. The Siemens continuous current machines feed the 60 arc lights, so that for every machine there are five lamps supplied with 9 amperes at about 45 volts. Two of such machines serve as reserves. All the machines are connected by means of underground wires to a commutator, from which the leads go to the

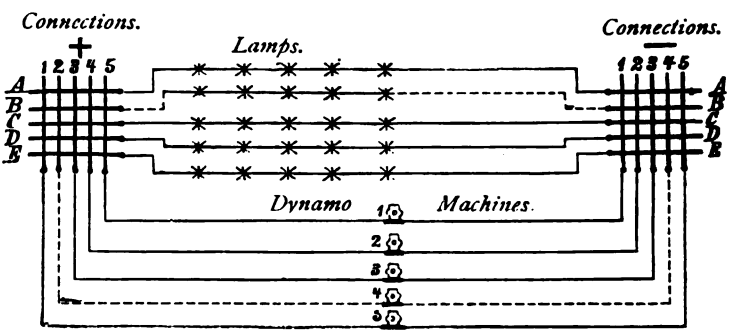


Fig. 541.—Plan of the Circuits.

several lamp circuits. Fig. 541 shows the arrangement for five machines and 25 lamps. The positive brushes of the machines are connected with the metal rails 1 to 5 of the commutator marked +, the negative brushes with the rails 1 to 5 of the commutator marked −. The metal rails crossing each other at right angles are well insulated from each other, and are connected with the corresponding poles of the lamp circuits. These rails can be joined in couples by having a plug inserted at the point where they cross. This arrangement permits the connection of any of the lamp circuits with the different machines. If, for instance, it were required that machine 4 should feed the lamps of circuit B, plugs would have to be inserted at the point of crossing of rails A and B, at the + and − ends. The leads are all underground; but those of the arc lamps consist of Siemens' patent cables having a length of 13,000 metres. The currents intended to feed the glow lamps have first to pass a regulator, so as to obtain a constant potential between the poles, and then to pass through the leads as constructed by Edison, which have been already described. The lamps for the arc light are Siemens' differential lamps for continuous currents; they have carbons 11 millimetres in diameter, and 200 and 380 millimetres in

length, which are capable of burning from ten to eleven hours. Outside the buildings the lamps have the form shown in Fig. 542. Platforms and halls have

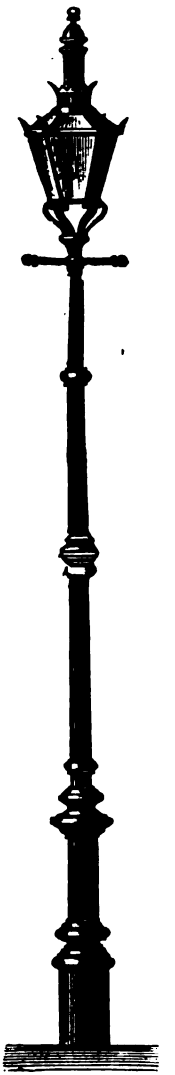


Fig. 542.—Strasburg Pedestal Lamp.

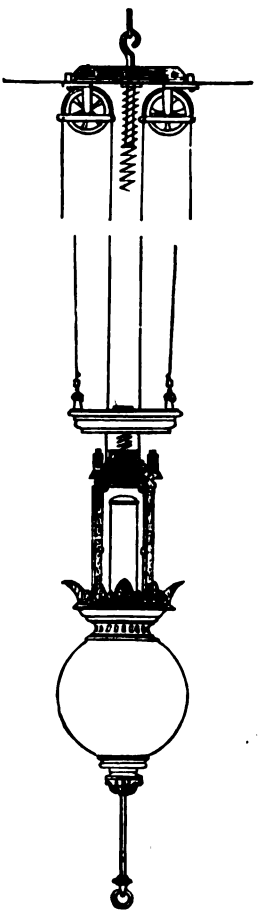


Fig. 543.—Strasburg Hanging Lamp.

lamps as shown in Fig. 543. Supports for the Edison incandescent lamps have been furnished by the firm of Schäfer and Hauschner. All the glow lamps of 10 or 16-candle power are constructed for the same potential.

Lighting in Railway Trains.—The electric light may not only be used advantageously for the lighting of railway stations, but also for the lighting of the rolling stock. A description of the locomotive engine-lamp, by Sedlaczek-Wikulill, has been given already; this lamp is placed in a lantern containing a reflector, which is fastened to the chimney of the engine. The lamp can be moved sideways from the place of the engine-driver, to throw light on curves, etc. By means of a light of 4,000 normal candle power it is possible to see as far as two kilometres, and the lights of signals are not at all affected, but are distinctly recognised at great distances. In spite of the jolting to which the

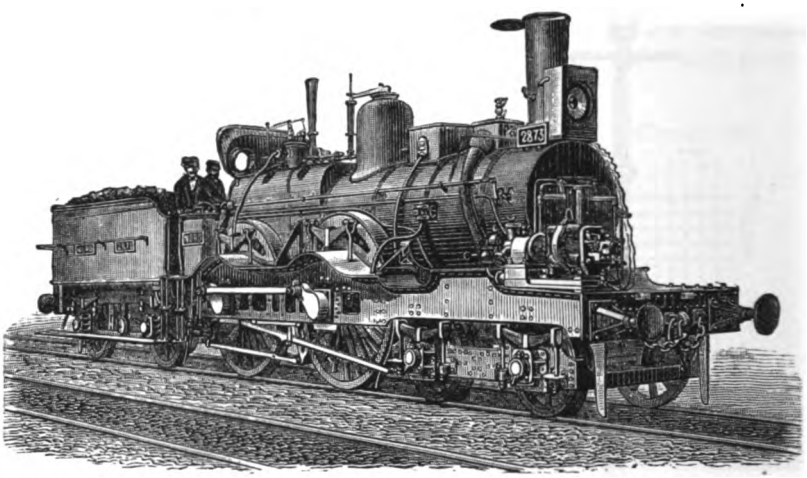


Fig. 544.—Electric Light on a Locomotive.

lamp on the engine is exposed, it burns with a steady and quiet light. The current for the lamp is supplied by a Schuckert flat-ring machine, which is set in motion by a Brotherhood steam-engine, which receives steam from the boiler of the locomotive engine. The lights on steam engines are generally fastened in front of the boiler, as shown in Fig. 544. The chief engineer, M. Pollitzer, says in his report of the Exhibition at Vienna: "Such an arrangement is of great importance for tunnel examinations, night work, etc.; it is also the cheapest system of electric lighting, because no separate steam generation is required."

Lighthouses and Harbours.—The electric light is used for lighthouses, on ships, harbours, etc. Experiments with electricity for this purpose were made for the first time under Faraday's direction, at Blackwall lighthouse, in 1857, then at the South Foreland in 1858, and at Dungeness in 1862. The result was not at first very satisfactory, owing to the inefficiency of the machines, but the results obtained later on by means of the Alliance machines gave rise to renewed studies and experiments. Lighthouses are not only distinguished from each other by

their lights, but also by the manner in which they display them; as regards the intensity of their light we distinguish between lighthouses of the first, second, and third order, etc. Lighthouses of the first order have large lights, and are used at points of importance. The light of some is arranged so as to light up the whole of the horizon; of others two-thirds of the horizon; and so on. The seaman must also be able to recognise the different lighthouses by the peculiarity of their lights. We have, therefore, lights that increase and diminish in intensity; others that give out coloured lights at certain intervals, etc. The distance that these lights can be seen depends upon the intensity of the light itself, its height above the sea-level, and the medium. Fog diminishes the distance considerably. The distance through which the light is seen will still further be diminished if the source of light be richer in violet than in red rays. Electric light, being richer in violet rays than the light of an oil-lamp, will be considerably more weakened through fog than the latter; practically, however, the electric light, even under these circumstances, is superior to oil, owing to its far greater intensity. To send the concentrated light in the desired direction, concave metallic mirrors were formerly used; practice, however, soon proved these to be easily affected by atmospheric influences. In place of a reflecting apparatus, refracting discs are used at present, *i.e.*, apparatus consisting of glass lenses and prisms, arranged on a plan suggested by the celebrated physicist Fresnel. These compound lenses have been manufactured for some time by the firm of Sautter, Lemonnier, et Cie., Paris, also by Messrs. Chance, in Great Britain; but have recently been also manufactured by the Vienna firm of E. Kraft und Sohn. Fig. 545 represents the optical apparatus constructed by the Paris firm for the lighthouse on the island of Razza, in the Bay of Rio Janeiro. The light consists of two white flashes

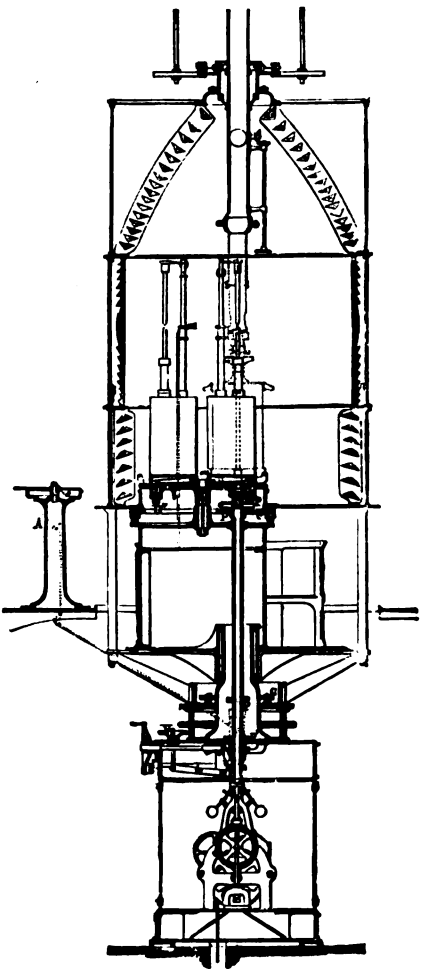


Fig. 545.—Apparatus for Lighthouse.

and one red, at an interval of fifteen seconds between each series of flashes. Underneath the lantern, which is 3·5 metres in diameter, is placed the motor from which the motion is transmitted by means of the tube *p p*, and toothed wheels. By means of the lever A the optical apparatus can be arrested in its motion. The screws *g* serve to centralise the apparatus. As it is essential that the light should not be interrupted, precautions have been taken accordingly. Should the lamp become inactive, it is easily replaced by a second one. The platform upon which the lamp is placed moves about a vertical axis in such a manner that the second lamp can easily be made to take the position of the first. To guard against unforeseen circumstances an oil-lamp is also arranged on a support, which can be brought to take the position of the first lamp by moving the platform. The oil-lamp in the figure has dotted lines. Two Gramme continuous current machines supply currents, one of which serves as an auxiliary. As motors, two 10 horse-power steam engines, by Chaligny, are used. At some of the French lighthouses Alliance machines are still in use; at present, however, magneto-electric machines by De Méritens are preferred for this purpose.

The lighthouses at La Hève stand on the high rock of the same name; but they themselves are only of moderate height; between the towers, which are about 60 metres distant from each other, is the machine house, containing four Alliance machines—two machines for each tower. For ordinary purposes, however, only one machine is required for each tower, and only during fogs, storms, etc., are both machines worked. Each tower has four lamps, but this has proved an unnecessary precaution. Fig. 546 represents the lighthouses as they appear at night.

Lighting of Ships.—The electric light is of great service on board ship, and especially for purposes of reconnoitring, etc., on war vessels. The greatest mission of the electric light in a future war, no doubt, will be the warding off of torpedo boats, and to this use great attention is being paid by all nations. The torpedo boats are from 30 to 40 metres in length, by a breadth of about 2 metres, and less than 1 metre water draught. In the fore portion of the vessel is arranged the apparatus for throwing the torpedo overboard. Considering that these little boats move with great rapidity, and are not easily detected, as they emit no smoke from their chimneys, means must be found to prevent their approach. The idea of surrounding the man-of-war with nets, etc., has been given up as impracticable, as the net might easily be caught by the screw, etc.

If torpedo boats are to be made harmless, they must be made visible, which seems only possible by means of a powerful electric light. Hence men-of-war must be provided with the electric light. The machine most frequently in use for marine purposes is the Gramme continuous current machine. The German navy uses Siemens machines, and quite recently the Chinese ironclad, *Ting-Yuen*, has been provided with Schuckert machines. For motors, high-speed steam engines are mostly used, the shafts of which are directly coupled to the shafts of the light machines. Such motors are

Fig. 546.—Lighthouses at La Hève.

constructed by Brotherhood, Dolgoroucki, and Abraham. These motors, as a rule, are supplied with steam from the ship's boiler; it is, however, better to use separate boilers, so that the light may be used at all times. As regards the style of lamps, those are most frequently used that can be regulated by hand, because the mechanism of most lamps does not act

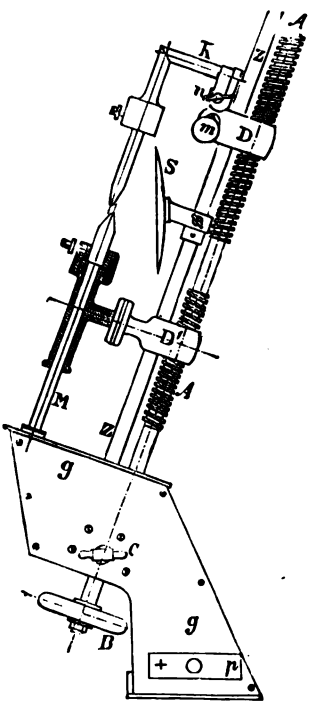


Fig. 547.—Mangin's Regulator.

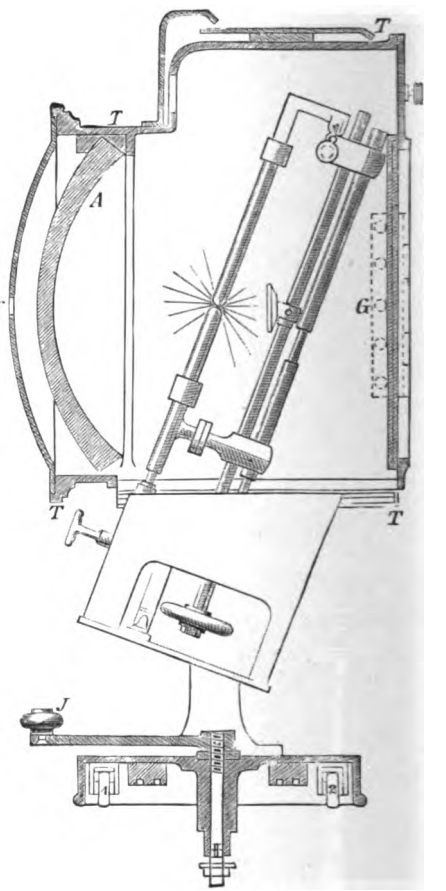


Fig. 548.—Mangin's Projector.

reliably, owing to the motion of the vessel. For signal lights, however, a hand regulator would not be practicable, and for this purpose the lamp by Sedlaczek Wikulill will prove of service.

Mangin's Projector.—The lamps by Sautter, Lemonnier et Cie., and projectors by Mangin, shown in Figs. 547 and 548, are mostly used for navies. The lamp is fastened to a metallic case *g g*, bent at an angle of 30°. This position

Fig. 549.—Mangin's Projecting Lamp in Use.

is necessary, owing to the irregular emission of light rays from an arc produced by continuous currents. To light the lamp, the upper carbon-holder K is brought into the desired position by means of the joints *m* and *n*; the wires are then fastened to the pole-clamps of the lamp, and the double screw A A is turned by means of wheel B until the two carbons touch each other. B is then turned in the opposite direction, and then the arc is produced. By turning B the carbons will move away from each other, because the threads A A

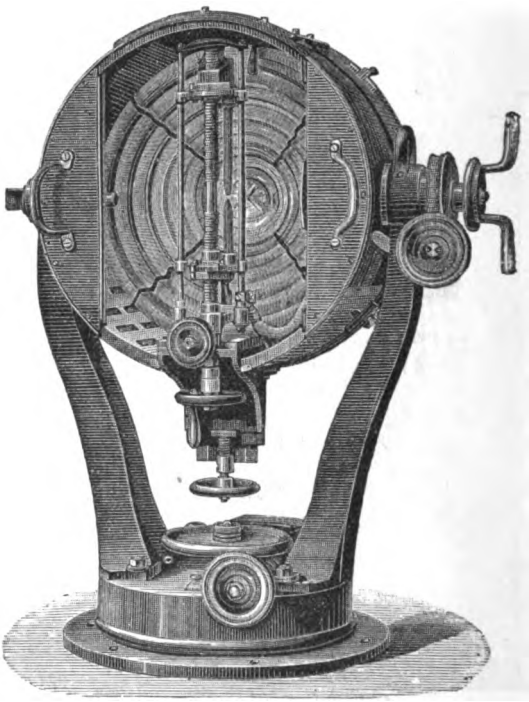


Fig. 550.—Schuckert's Projector.

are cut in opposite directions. In order to keep the burning point constant as regards position, the threads of the screws have to be cut in the proportion of 1 to 2, because the carbons are unequally consumed. Should the point move, it can be set right again by means of the screw C. The guiding rod Z Z prevents D D from moving.

Mangin's projector consists of this lamp, placed in a cast-iron, well-ventilated drum. The rays emitted by the arc are concentrated by the concave mirror A. Glass plates or lenses at G scatter the rays. A consists of a glass mirror, silvered on its convex side. By means of two axes any position may be given to the apparatus. If the arc is exactly opposite to the focus of the mirror, the pro-

jector will send out parallel pencils of light; but if the lamp is moved in any other direction, the projector will produce a scattered or more centred light. The effect of such a projector is shown in Fig. 549. Besides the Mangin projector, the Austrian navy makes use of an auxiliary projector, devised by the engineer M. Burstyn; this auxiliary projector consists of a metal tube, which is fastened sideways to the projector, and inside this metal tube there is a plane mirror, movable in all directions. By means of this apparatus light can be thrown upon objects by the side of the main stream of light. The projectors by Sautter, Lemonnier et Cie., Siemens, and Schuckert, which are furnished with a system of lenses, serve the same purpose as Mangin's.

Schuckert's Projector.—This apparatus has been constructed for the Chinese vessel *Ting-Yuen* by Schuckert; the back view of this projector, with the door removed, is shown in Fig. 550. The lamp is similar to the one just now described; the two guiding rods are insulated above and below, and the lower guiding piece is insulated from the screw. The current passes through the metallic portions of the projector into the screw and the upper guiding piece, and so through the carbons and the flexible cable, which is connected with the right-hand guide-bar leading to the pole-clamp. The lamp can be moved in various directions by means of slides and thermometer screws, for the purpose of centring the arc. The rays of light are caught by a mirror fastened to the guiding rods of the lamp (left out in the figure), and thrown back upon the lenses. A dispersing lens might be placed before the Fresnel lenses, in order to spread the pencils in a horizontal direction.

Most of the larger steamers are lighted inside by electric light, especially English and American ships. The following may serve as examples:—

The Lighting of Passenger Ships.—The packet *City of Richmond*, of the Inman Line, has been lighted since 1881 with Swan lamps; the *Servia*, of the Cunard Company, with lamps by Swan and Siemens, having a Siemens dynamo machine, which is driven by a Brotherhood motor with three cylinders. The steamer *Château Leoville*, sailing between Bordeaux and New York, the property of a French company, is lighted by Swan lamps. The large packet boat *Austral*, belonging to the Orient Company, by Siemens lamps distributed over the saloon, machine-room, offices, and passages. The yacht *Namouna*, the largest and finest private steamship of America, built purposely for Mr. J. Gordon-Bennet, director of the *New York Herald*, has 120 Edison B lamps, each of eight normal candle power. The light machine is driven by its own motor, which receives steam from the ship's boilers. The large steamer *Arizona*, sailing between Liverpool and New York, is lighted by 300 Swan lamps, for which two Siemens continuous current machines supply current. Shark's Caledonian machines, which transmit their power by means of ropes, are used to drive these light machines, as shown in Fig. 551. The electric apparatus for the packet *Normandie* was furnished by the firm of Siemens, London. To light the machine-room, boiler, goods-rooms, and out-places, sixteen differential lamps are used. 390 Swan lamps light the cabins,

passages, and saloons. Two continuous current machines and one alternating current machine furnish currents for these lamps, as well as a secondary battery

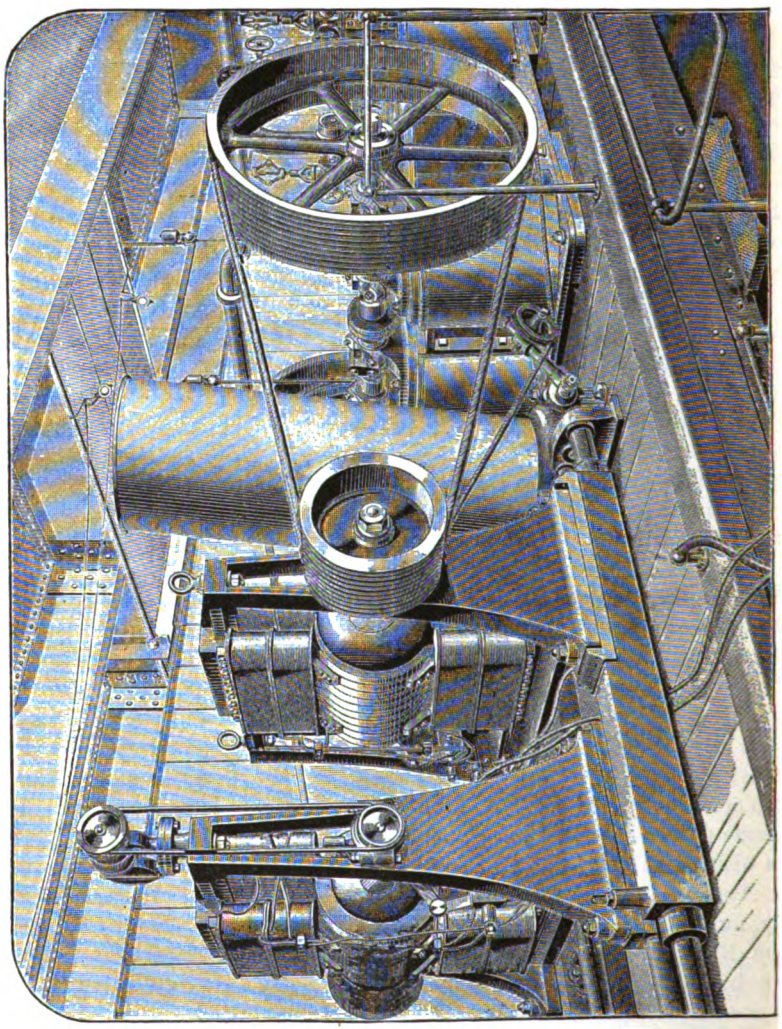


Fig. 551.—Machines for Lighting the Steamer *Ariadne*.

of fifty Faure's elements. Each of the continuous current machines is capable of supplying 300 Swan lamps with current, so that only one machine need be worked, and the other can be kept as a reserve. The alternating current machine feeds ninety Swan lamps and the sixteen arc lamps, of which twelve can be used at the same time. The dynamo machines are driven by steam

engines which are independent of each other. The secondary elements are intended for use in cases of accident, or while the dynamo machines are undergoing repairs, and may be charged by either of the continuous current machines.

The electric light for river steamers is of importance, especially when frequent and sudden bends have to be passed; as an instance we may mention Menier's yacht, which passes the bends of the Marne and Seine without danger, owing to its electric light, which is furnished with a projector.

The Lighting of Harbours.—Harbours where ships can enter only with the tide, require strong light. In order that ships may enter the Havre harbour both by day and by night, the electric light has been adopted; at present there

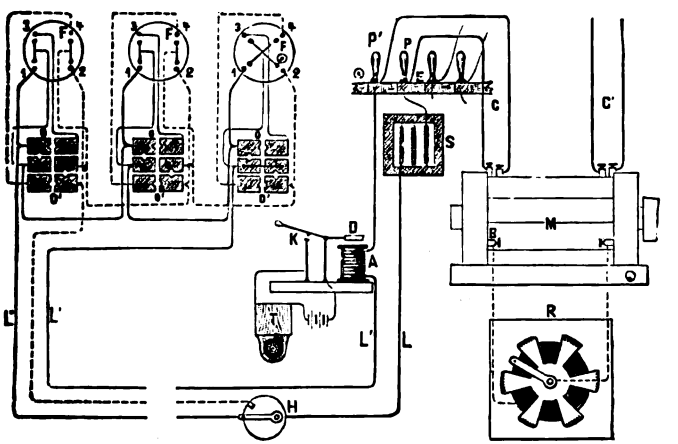


Fig. 552.—Arrangements at Havre Harbour.

are twenty-four lamps, arranged in six circuits. Two steam engines of thirty-five horse-power drive four alternating current machines by Gramme: one of these Gramme machines works, as a rule, in an open circuit, and serves as a reserve. Two circuits leave each dynamo machine, and all the circuits are arranged in the same way. Fig. 552 represents one of these circuits. M indicates the dynamo machine, with its two circuits C and C'; R is the resistance box inserted in the circuit of the electro-magnets for the regulation of the currents in the two circuits. C leads to the plugs P P' of the general commutator for all the circuits, so that in case one of the machines should break down, the auxiliary machine might be immediately inserted. The leads leaving at E have first to pass the resistance frame S, which serves the purpose of equalising the currents in the two circuits of one machine; this is necessary, owing to the unequal lengths of the two circuits. L' leads to the commutator H with two contacts, from which the leads L'' and the dotted leads are conveyed to lamps F F F (for simplicity's sake only three lamps are drawn instead of six). The current is conducted back through the leads L', in which the electro-magnet A

is inserted, where it causes the armature D to be attracted. If, however, the current in the lamp is interrupted—as, for instance, by the extinction of a lamp—the armature D falls off, making contact at K, and causing the bell T to ring. Each lamp bears four Jablochkoff candles with carbons of 6 millimetres, but the two first lamps have two supports of two candles each, and have, therefore, two back wires. In the foot of each candle-holder there is a commutator o o′ of six plates, which the current has to pass. This complicated arrangement serves a double purpose: first, the current might, with the help of commutator H, be sent at any moment from the machine-room into the candles 1 or 2; secondly, by changing the plugs of commutator o o′ the candles 3 may be connected with the leads. The current will flow first through the leads L, commutator H, leads L″, and then into candle 1 of the first lamp, candle 1 of the second lamp, and so on; it then passes over L′, A, P′ back to the machine. When the candles 1 are consumed, or extinguished from other causes, the current is interrupted in the leads L L′, and the bell T begins to ring. By moving the lever of commutator H to the second contact, the candles 2 will be made to burn. The current now flows in the following way:—From L over H, through the dotted leads into candle 2 of the first lamp, then into candle 2 of the second lamp, and so on, returning through lead L back again to the machine. An attendant goes from candlestick to candlestick, and by insertion of the plugs connects the two upper metal pieces of commutator o o′, preparing the passage for the current into candles 3. By turning the lever of commutator H (into the first position), the candles 3 will be made to burn. The current will flow as follows:—Through L L″ into the upper metal piece to the left of the first commutator o o′, through the plug, into the metal piece to the right, then to candle 3 of the first lamp, and so on: and then back through leads L′ to the machine. After these examples, it is easy to determine the direction of the current for candles 4. All four candles might be made to burn during the same night. When no interruption takes place, only two are needed, as the light is only required during three hours. To take a lamp out of circuit, the upper metal piece to the left and the lower metal piece to the right are connected with the middle pieces, which are opposite to them, by means of trunnions. The rest of the circuits are arranged like the one just now described. All the leads go to the general commutator E, which is placed in the machine building, along with the numbered electro-magnets A and commutator H. Fig. 553 is intended to give an idea of the general effect obtained by this arrangement.

Street Lighting.—Electric lighting for streets and public places is more used in America than in Europe; but not only are the streets of New York lighted by electricity, but also those of very much smaller towns. A greater regularity, however, has been attained in the systems adopted in European towns—as, for instance, in the Leipziger Strasse, Berlin—so that the greater use of electric lighting for streets in America than in Europe, must be due to other causes than greater perfection from a technical point of view.

Fig. 553.—Electric Illumination at Havre Harbour.

The first trial for public places and streets was made in 1877, in the Avenue de l'Opéra, Paris; the Jablochkoff candles used here, however, did not give satisfactory results, owing to the unsteady and coloured light produced. In 1879 Siemens and Halske had a trial lighting of the Kaiser Gallerie, Berlin, using a divided arc light for the first time in the differential lamp. The differential lamp, as we know, allows the insertion and removal of lamps without disturbing the remaining ones in the same circuit.

Lighting of the Leipziger Strasse, Berlin.—Without going into details, we shall give the description of a system which has been in use for two years, and has given perfect satisfaction; we mean the arrangements for the electric lighting of the Leipziger Strasse, Berlin. The apparatus

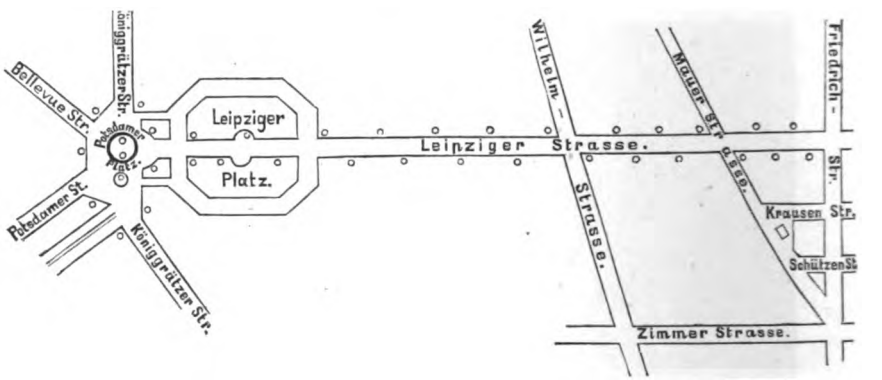


Fig. 554.—The Leipziger Strasse, Berlin.

consists of four dynamo-electric machines (Siemens and Halske), each of which is capable of furnishing current for twelve differential lamps. To drive these, four Otto-Langen's gas engines of 12 horse-power are used, which are independent of each other, and drive one light machine each. One of the machines with its gas motor is not used, but kept as a reserve. By means of the general commutator each of the machine systems can be connected with any of the lamp circuits. The whole of the machinery is contained in a building in the Wilhelm Strasse. The leads are underground, and consist of three circuits, which are independent of each other, and whose respective lengths are 1,974, 1,887, and 1,480 metres. The distance from the machine building to the nearest lamp is 350 metres. The cable for the leads consists of a copper wire of 3·4 millimetres diameter, covered with a prepared jute insulation; over this lead is wound, and then again tarred jute; to prevent wilful damage the cable has been covered with bricks. The distribution of the lamps may be seen in Fig. 554. The lamp supports have the form of Fig. 542, and stand at a distance of 7·5 metres from each other, and are 5·5 metres high; twenty-five lamps light a part of the Leipziger Strasse, 22 metres wide and 820 metres long;

eleven lamps give light to the Potsdamer Platz. The carbon rods have a diameter of 11 millimetres, and burn nine hours, which is sufficient, as the lamps need only burn till midnight. The intensity of each lamp is 880 normal candle power, measured under an angle of 30 degrees. The city of Berlin had to pay 26,040 marks for the first year to the firm of Siemens and Halske. The working expenses came to 13,906·41 marks; repairing, 540·41 marks; salaries, 3,836·34 marks; rent, etc., 781 marks; lamp carbons 5,472·85 marks: *i.e.* a

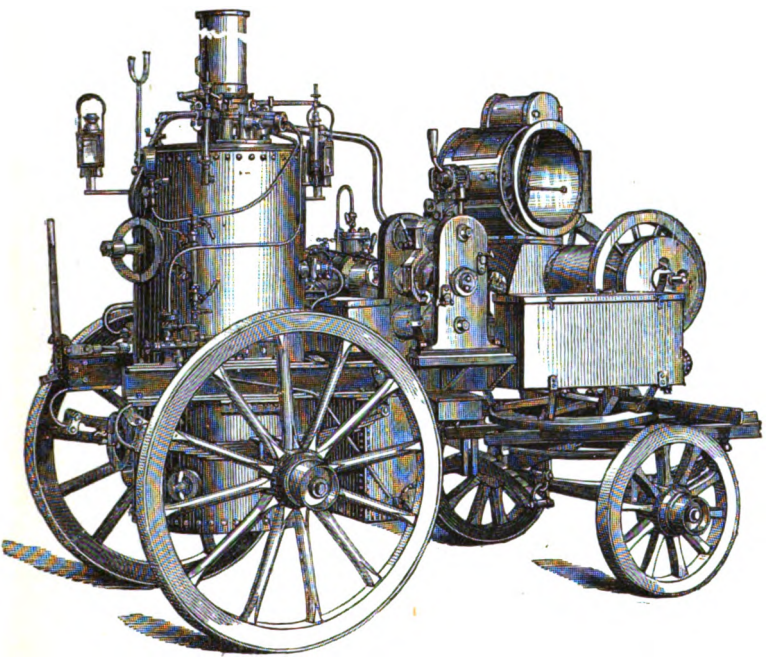


Fig. 555.—Portable Electric Lighting Apparatus.

total of 24,537·01 marks from 20th September, 1882, to 20th September, 1883. The technical results for the first trial year were regarded as perfectly satisfactory. Bricks were not found to be a sufficient guard against damage to the cables, but this was quite easy to remedy, either by laying the cables deeper than 0·5 metres, or by using a better means of protection.

Transportable Lighting Apparatus is of great importance in cases of accident, such as the giving way of bridges, etc. Such lighting systems are especially of value for military operations, artillery attacks, sieges, reconnoitring purposes, etc. etc. The French and German armies already possess such lighting carriages. The apparatus used at present by the French army consists of forty lamps of the largest kind (*i.e.* of an intensity of 30,000 normal candle power) intended for the defence of the coast and fortresses; twelve

of medium size, of 19,200 normal candle power, and eight of 12,000 normal candles. A movable lighting system as constructed by Sautter,

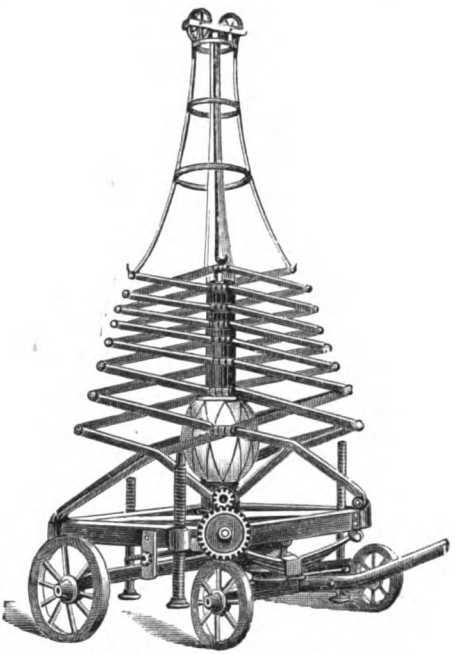


Fig. 556.—Schuckert's Portable Pedestal.

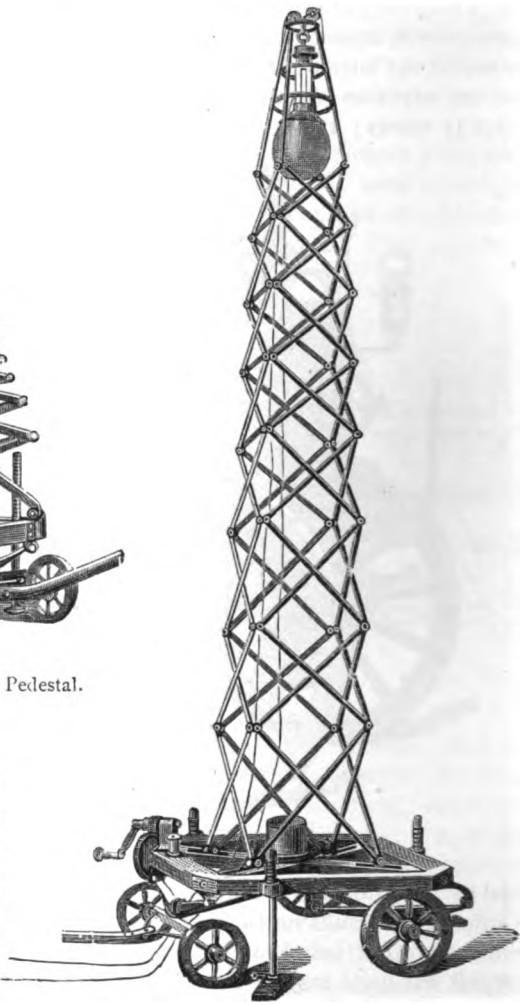


Fig. 557.—Schuckert's Pedestal Extended.

Lemonnier et Cie., is represented in Fig. 555. Upon the four-wheeled carriage-frame a Field boiler is placed, an eight horse-power steam engine by Brotherhood, and a continuous current Gramme machine for 12,000 normal candles. Beside the Gramme machine is placed a Mangin projector, the cable, and a box containing tools. The projector, however, is not fastened to the carriage-frame, but may be placed at any distance up to 1,000 metres. The German army uses Siemens machines, which are driven by steam engines by Dolgoroucki. The apparatus constructed by Schuckert, and by Mesthaler and Co., differs in several particulars from the one described. The steam engine, which drives a Schuckert flat ring machine, is placed upon a four-wheeled frame. The lamp (by Piette and

Krizik) is placed upon a separate little carriage, having a frame-work as shown in Fig. 556. The lamp is easily lifted by means of wheel-work. The lifting of the lamp to a height of 10 metres, as shown in Fig. 557, takes only five minutes. Experiments made with this apparatus during the Exhibition at Munich showed that twenty minutes were sufficient for having it in perfect working order.

In certain cases only very small lights are required, but lights that must be enclosed in air-tight globes; such lights, for instance, would be serviceable for rooms containing explosive matter, and coal mines. To the oldest movable electric lamps, if this name may be applied to the apparatus, belongs the lamp devised by Dumas and Benoit (Fig. 558). It consists of a Geissler

Fig. 558.—Dumas's Portable Lamp.

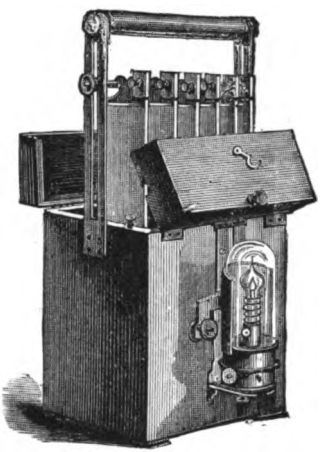


Fig. 559.—Puluj's Portable Lamp.

tube, having the form of a spiral, enclosed for protection in a cylinder. The Geissler tube is made to glow by means of an induced current. The induction apparatus is placed in the leather case together with two elements. This apparatus, however, ought not to be used in places containing explosive gases, in consequence of the high potentials of the induced currents; for, in spite of the most careful insulation, sparks might be produced which would cause an explosion of the gases. Fig. 559 represents a lamp by Puluj; it consists of a little wooden or ebonite box, 20 centimetres wide and 25 centimetres high, in which six Daniell elements are placed. To diminish the inner resistance of the elements, linen sacks were substituted for the earthenware cells. The zincs can be taken out of the sulphuric acid and hooked to an iron rod. A glow lamp is fastened to one side of the box. For concentration of the light a little metal reflector may be placed behind the lamp. The lamp has an intensity of from six to seven normal candles, and the smallest model burns from six to seven hours. The complete apparatus weighs seven kilogrammes.

Wächter's Mining Apparatus.—Puluj's lamp may be used with advantage in most of the above-mentioned cases, but for exploring mines the apparatus constructed by Wächter, and shown in Fig. 560, is used. At the right hand of the operator in the figure is placed the apparatus which supplies the air for breathing; a thick gutta-percha tube, which may have a length up to 100 metres and more, leads to the waist of the man, and from this a thin tube runs over the back to the mouth-piece. The lamp may be held in the hand or fastened to the coat. The weight of the lamp is 300 grammes. A silken

Fig. 560.—Wächter's Mining Apparatus.

string, having a double metallic wire, leading from the waist of the man to the lamp, allows it to be moved about. The electric current is conveyed along two insulated copper wires, which are arranged inside the linen cover of the gutta-percha tube. To the belt of the man a key is fastened, which, when pressed, causes an electric bell, fastened to the box of the galvanic battery B, or a hand machine placed near the air-pump, to ring, and by signal indicates whether too much or not sufficient air is sent through the apparatus. The bell serves also as a signal in case the lamp should go out or break, and it only ceases ringing when the cause of disturbance is removed. As the source of electricity Wächter prefers a small hand machine to any kind of battery (as, for instance, a Gramme machine, Fig. 232). The machine is always ready for use, whilst a battery has first to be filled, and might, in the hurry, give rise to such irregularities as bad contacts, etc. The attention of the authorities of fire brigades, theatres, and other similar institutions, should be drawn to Wächter's life-saving mine apparatus.

Medical Uses of the Electric Light-Specula.—The science of medicine owes much to the artificial sources of light for means of examining such portions of the body as cannot be directly seen. As instances we may mention the larynx mirror used by Liston, 1840, and reintroduced by Czermak, 1858, and the eye mirror (speculum oculi), with the help of which Helmholtz obtained for the first time a sight of the structure of the living eye, etc. As a rule, day-light or a lamp is used for such examinations, the rays being concentrated by means of a concave mirror; but, as we shall now show, the use of a glow light in such cases is extending. A second method of making the body under examination visible is to introduce the source of light itself, and for this purpose the electric light alone can be used.

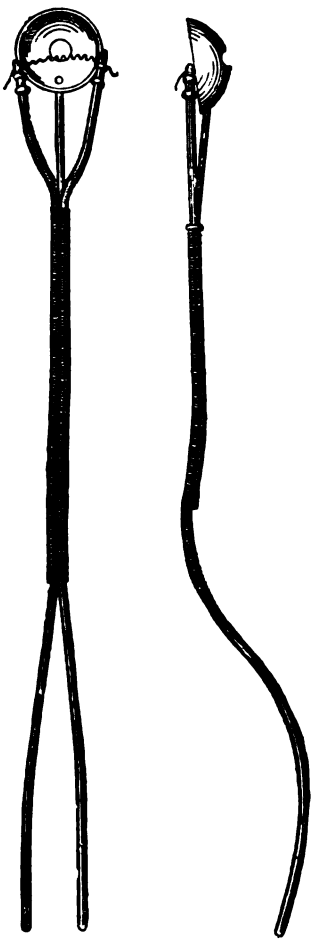


Fig. 561.—Aural and Nasal Apparatus.

Fig. 562.—Frontal Apparatus.

Hedinger, in Stuttgart, uses for the examination of the ear and nose the simple apparatus with reflected light shown in Fig. 561. It consists of a small concave mirror, before which a platinum spiral is stretched, the ends of which are connected with conducting wires insulated from each other and leading to a large-surfaced battery. When contact is made, the wire becomes heated, and by means of the concave mirror sends the light to the place under examination. The mirror has a hole at its optical centre for observations. More recently an apparatus

with stronger light has been exhibited by several instrument makers, under such names as a Traumatoscope, Frontal-Photophore, etc. Fig. 562 represents such an apparatus consisting of a glow lamp placed in a short cylinder, which has a lens in front and a concave mirror at the back. The whole apparatus is constructed by Jirasko, of Vienna; it weighs from 300 to 400 grammes, and the lamp has an intensity of twelve-candle power. If the light is to be introduced into a cavity, such as the stomach, the platinum wire has to be surrounded by a tube round which water circulates.

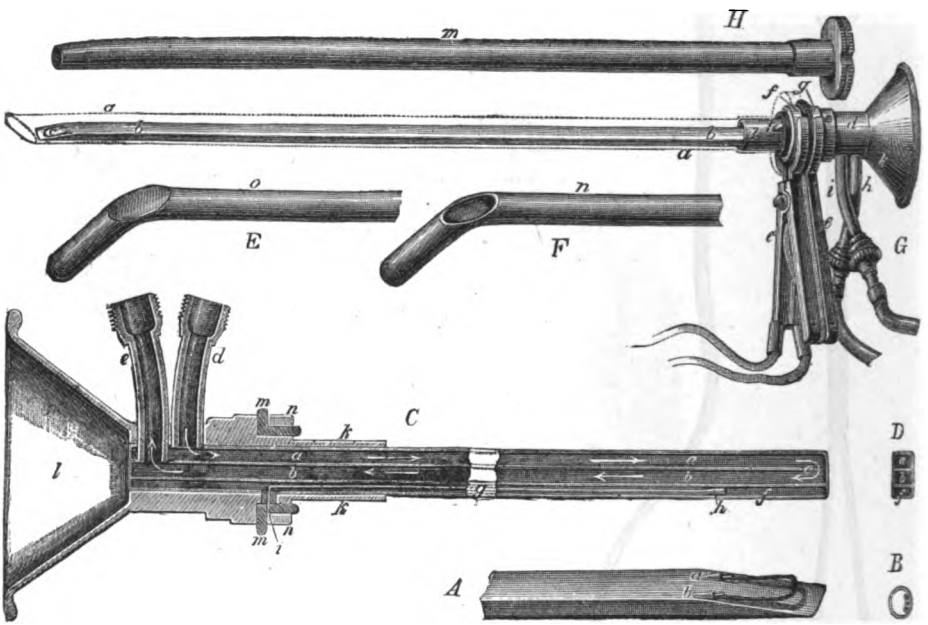


Fig. 563.—Leiter's Apparatus.

Leiter, of Vienna, has constructed a series of apparatus which differ in form according to the purposes they are intended to serve, but are similar in principle. To the metal holder *k k* (Fig. 563) is fastened the funnel *l*, and the silver rod with its three channels *a*, *b*, and *f*. Channel *a* is connected with the water pipe *d*, and channel *b* with the discharge tube *e*. The direction of the water is indicated by arrows. A silver wire *g*, terminating in a cup at *h*, enters *f* at *i*. To insulate this silver wire a fine capillary glass tube is placed over it. The cup *h* is made to hold one end of the platinum wire, as shown in the separate diagram A in Fig. 563. The second end of the platinum wire is fastened in the same manner; the cup is not insulated from the silver rod, and therefore is in electrical connection with the metal holder *k k*. D represents a cross section of the rod C. G shows the instrument ready for use. The observation tube *a a* is drawn separately; the

water circulates through the tubes *i* and *h*. Contact is made and broken by means of the spring clip *e e*. The lighting rod, as may be seen from the cross section, takes up only a very small portion of the observation tube. F and E represent the different forms of the observation tubes.

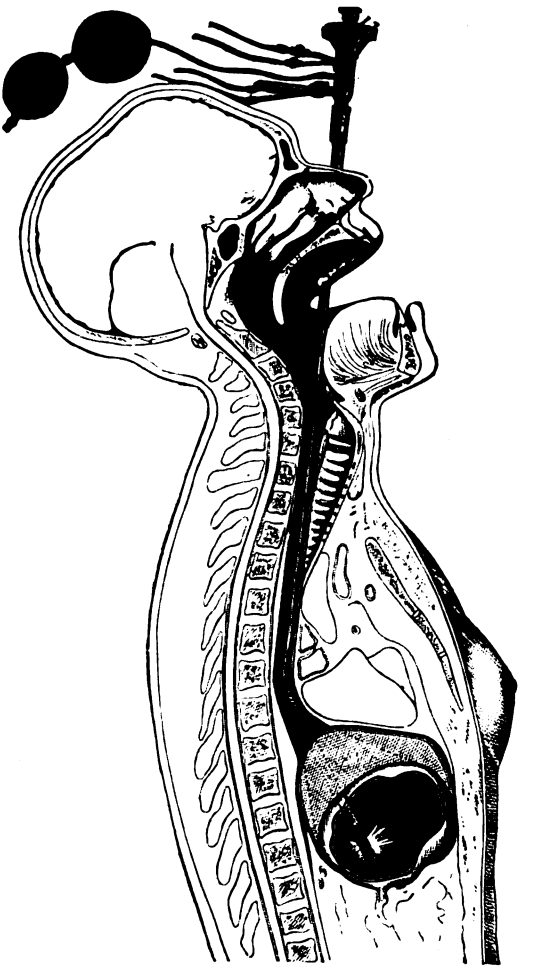


Fig. 564.—Gastroscope in Use.

The gastroscope has to be bent, as shown in Fig. 564. Prisms arranged in the bend of the tube allow an insight into the stomach. The arrangements for current and water supply are the same as already described. The gastroscope has, however, in addition a fine channel through which air is forced by means of india-rubber balls, in order to inflate the stomach

ELECTRO-CHEMISTRY AND METALLURGY.

History.—Päts van Trostwyk (1789) pointed out that electricity was capable of decomposing water; to show this he used gold wires, which he allowed to dip in water, connecting one of them with the inner, and another with the outer coating of a Leyden jar, and passing the discharge through the water. The gas bubbles collected proved to consist of oxygen and hydrogen gas. Wollaston used (1801) fine gold wires, fused in little glass tubes or covered with sealing-wax, one of which was connected to the rubber, the other to the conductor of an electrical machine. He dipped the points of these into water, and oxy-hydrogen gas was evolved by turning the machine. If silver wires were allowed to dip into a solution of copper sulphate, the wire connected with the rubber of the machine was found to be coated with copper. In 1843 Armstrong proved, with the help of the steam electrical machine, that electricity decomposes water into its elements, viz., H and O. Although, from a scientific point of view, these experiments are of interest, no practical value has been derived from them.

In 1805 Brugnatelli, Professor at the University of Pavia, showed that by means of the current from a Volta pile silver coins may be coated with a layer of gold; he made use of an ammoniacal solution of chloride of gold, in which the coins to be gilded were placed, being connected by means of a silver wire with the negative pole of the pile, while the positive pole was in direct connection with the gold-bath. Almost at the same time Jacobi, in Dorpat, and Spencer, in Liverpool, made their discovery of electrotyping. In February, 1837, Jacobi observed, in experiments made with a galvanic battery, that different layers of copper could easily be separated from the negative electrode; struck with the exactitude with which these copper layers had imitated forms of electrodes, he at once made use of his discovery for practical purposes. In 1838 Jacobi laid before the Academy of St. Petersburg copper-plates, which were the imitations of drawings engraved upon other copper-plates. The Emperor Nicholas allowed the inventor the necessary means for the further perfection of his process (1840). In the same year Spencer had obtained similar results. De la Rive was the first who introduced electro-plating in commerce. In 1846 Boettger produced iron deposits, and in 1859 Jacquin discovered how to cover copper-plates with steel. In recent times electrotyping in iron has been brought to high perfection by Klein at St. Petersburg, whose bas-reliefs exhibited during the Exhibition at Vienna, 1883, were very much admired. The firms of Christophle, Paris, and Elkington and Mason, Birmingham, have already brought this branch of electro-manufacture to high perfection.

This branch of industry may be divided into three groups, viz., electro-chemistry, electro-metallurgy, and electro-deposition.

ELECTRO-CHEMISTRY.

Electro-Dyeing. — Many of the dyes used at the present time are obtained from coal-tar, either by reduction or by oxidation. For these reactions, Goppelsroeder, of Basel, makes use of electricity, thus introducing *electro-dyeing*. Goppelsroeder, in various experiments, has succeeded in (1) forming and fixing dyeing matter upon different fibres; (2) tracing white patterns upon a coloured ground; (3) placing patterns of different colours upon a coloured ground; (4) preventing oxidation of the colours during operation; (5) preparing a solution of the reduced or hydrogenised dyeing matter.

The formation and fixing of aniline black upon cloth or paper is brought about in the following manner: The cloth is saturated with a diluted solution of an aniline salt, and then placed upon an insulated metal plate; this plate must not be capable of being influenced by the reactions which take place. One pole of a battery or electric machine is connected with the plate which is placed upon the wet cloth, and has the pattern or writing drawn upon it, and is then connected with the second pole of the machine; when the current passes through the plates, a black copy is produced upon the cloth. The time required for the current depends upon the conductivity of the solution of the aniline salt, the temperature, the strength of current, etc., but need not exceed one minute or so.

If, instead of being connected with the plate, the second pole of the machine is connected with a carbon pencil, or some substance not acted upon, it is possible to write with the pencil upon the saturated cloth almost as quickly as with an ordinary pencil. The writing or drawing thus produced is probably fixed upon the fibres. To prevent the writing from running, substances such as gum or glue are added to the aniline solution, in order to make it thicker. This method may be employed for marking the pieces in bleaching, dyeing, and printing establishments, because this marking resists all further operations.

A similar method may be employed for destroying the colour. For this purpose cloth dyed with red or indigo-blue is soaked in a solution of chloraluminium, ordinary salt, or saltpetre. When the current is allowed to pass through the first two salts, chlorine is evolved; the nitric acid is liberated when saltpetre is used. Both chlorine and nitric acid convert the colours into white oxidation products, producing the desired tracings in white upon a coloured ground. These tracings may be obtained in other colours than those which represent the ground colour, by choosing such salts as form bases through electrolysis. This causes a new colour to be formed upon the parts acted upon, when the cloth is immersed in a bath of different colour, for it takes out the ground colour, and gives a different tint to the etched places. Goppelsroeder experimented thus upon cloth dyed with Turkish-red or indigo-blue, by impregnating it with hydrochloride of aniline. The current here etches away the original

colour and deposits aniline black. By this means drawings, writings, etc., in black may be obtained on red or blue grounds.

Metals are also used in printing, being fixed and deposited by means of the current upon the fibre. For this purpose the cloth is saturated with a solution of the prepared metal salt, and is then exposed to the effects of the negative electrode. The oxidation of the colours during the process is prevented by means of the negative electrode. To prevent oxidation of the colours in the vats, the negative electrode is allowed to dip into the colour-solution, whilst the positive electrode dips into a small vessel containing a conducting fluid. This vessel is connected with the vat, either by means of a simple tube, an earthenware cell, or parchment. The hydrogen evolved at the negative pole prevents oxidation of the mixture in the vat.

Goppelsroeder's Method of Indigo Dyeing.—To prepare indigo dye-base, Goppelsroeder proceeds as follows:—Indigo, finely powdered, is mixed with potash, and the mixture is placed partly in an earthenware cell and partly in a larger copper vessel; the earthenware cell is then placed in the copper vessel, and the latter connected with the negative pole of a battery or machine, while the positive pole, to which a platinum sheet is attached, is placed in the earthenware cell. The H given off at the negative pole converts the indigo-blue into indigo-white, which dissolves in the alkaline fluid. This conversion takes place at an ordinary temperature.

Electrical Bleaching.—The electrical current has been used by Naudin, W. A. Tichomiroff, and A. P. Lidoff for bleaching purposes. Chlorine is of great importance for bleaching purposes; but as it is difficult of transport in its gaseous form, or even in solution, a compound of a metal with chlorine is generally used, such as calcium, sodium, or potassium chloride. Chlorine is usually obtained either by heating a mixture of common salt, manganese dioxide, and sulphuric acid, or a mixture of HCl and manganese dioxide. Tichomiroff and Lidoff produce the hydrochloride direct from ordinary salt by means of the current. If a current is allowed to pass through a solution of sodium chloride, it is decomposed into its elements, viz., chlorine and sodium; the latter unites with the water to form caustic soda, which is acted upon by the chlorine set free, and hypo-chloride is formed. The quantity of this bleaching salt formed by the current not only depends upon the intensity of the current itself, but also upon the temperature, concentration, chemical property, etc., of the solution. As most metals are acted upon by chlorine, carbon is generally used for electrodes.

Potassium chloride is the most convenient for the preparation of bleaching liquids by means of the electric current. After the material to be bleached has been cleaned of fats, resins, etc., it is immersed in the fluid and left for some time. As HCl and free chlorine are produced and retained by the fibres, it is necessary that the cloth should be well washed after it is taken out of the bleaching liquid; the substances added to free the material from adhering chlorine are caustic soda, potash, or, still better, sodium bisulphide. Tichomiroff and Lidoff think that the material residues of salt lakes might be made use

of for bleaching purposes, and that the electrical machines could be driven by available water-power. Naudin and Bidet try to make use of electro-bleaching for commercial purposes in the following manner:—The vat M, Fig. 565, contains a salt solution, through which the current from the machine D is allowed to pass. The two electrodes E are not far from each other, so that the substances set free may be allowed to act upon each other. The sodium separated out at the negative electrode is converted into caustic soda, which again is reacted upon by the chlorine evolved at the positive electrode, and forms sodium hypo-chloride. The bleaching salt thus formed bleaches the matter

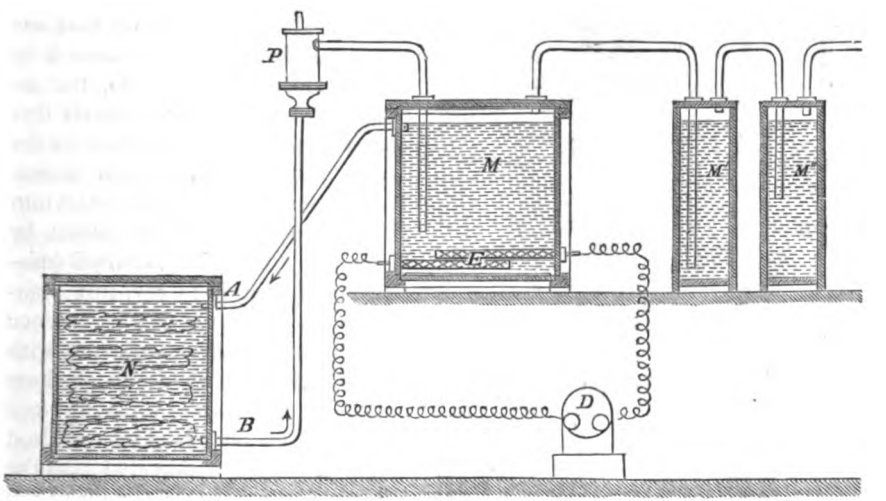


Fig. 565. – Electro-Bleaching Apparatus.

placed in vessel N, where the hypo-chloride salt again is decomposed, forming sodium chloride, HCl, etc. This fluid is then removed by means of the pump P through the tube B, back again to M, when it is again decomposed by means of the electric current. Neglecting certain reactions which take place during the passage of the electric current, the same chlorine may be used again and again to form the bleaching salt. As it is possible in this continued process to regenerate, so to say, the compounds of chlorine, this process might become practicable and remunerative for commercial purposes.

Rectification of Alcohol by Electricity.—Another application of electrolysis is that of the rectification of alcohol. This method was invented by Naudin, and introduced into Boulet's factory, at Bapaume-les-Rouen. Alcohol is obtained from potatoes, grains, and the refuse of a beetroot sugar manufactory, such as sugar-scum, molasses, etc. etc. During fermentation not only ordinary alcohol, but also larger or smaller quantities of the so-called homologous alcohols are obtained, which cause an unpleasant taste and smell, and

to which is given the name of fusel oils. Alcohol containing these fusel oils cannot be employed for many purposes, and it has, therefore, to be freed from them. The methods employed for depriving the alcohol of these impurities were oxidation of the fusel oils, conversion into compounds less disagreeable, or entire removal by means of carbon. The different processes of purification, however, are accompanied by considerable loss and increase of price. Naudin, according to his reports in *La Lumière Électrique*, has got rid of the fusel oils in alcohols in a far more economical way by means of electricity.

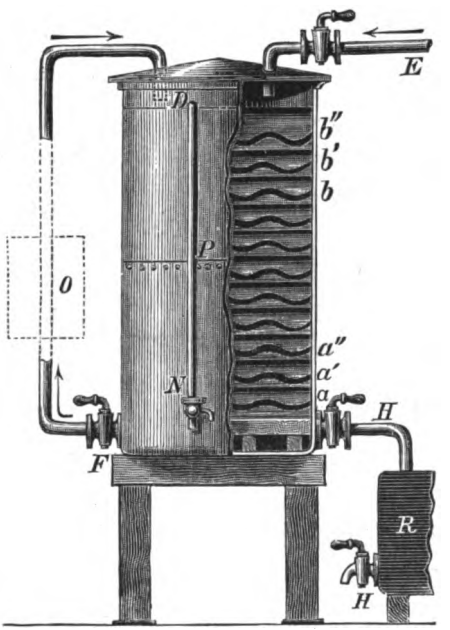


Fig. 566. – Electric Hydrogenator.

Naudin's Method of Rectification.—Naudin supposes that the bad taste and smell are caused by certain incomplete alcohols, the so-called aldehydes, *i.e.* compounds that are converted into real alcohols by the further addition of hydrogen atoms. The conversion of these aldehydes into alcohols can be brought about by hydrogen in the *status nascendi* (nascent state), that is to say, just liberated from combination, for experience shows that two bodies combine with greater readiness when one of them or both are in the act of separating out from a compound. Naudin's method of purification is subdivided into the following groups: (1) treatment of the first products of the distillation of the fermented liquid by a zinc-copper pile, *i.e.* by hydrogenation; (2) acidulation of these products by a thousandth part of sulphuric acid, and electrolysing in a series of voltameters; (3) neutralisation of the acid by zinc or iron; (4) rectification, according to one of the usual methods.

Hydrogenation of the first products of distillation takes place in vessel P, Fig. 566, which may consist of either wood or metal. In this vessel plates represented by the waved lines *b b' b''* are arranged above each other, but separated from each other by other plates represented by the lines *a a' a''*. To facilitate the separation of the hydrogen bubbles during reaction, the plates are perforated and inclined towards the bottom of the vessel. 105 rows of zinc plates are contained in a vessel of 150 hectolitres capacity, which represent a generating surface of 1,800 square metres, or 12 square metres to every hectolitre. The zinc plates have to be well cleaned; they are first washed with a solution of caustic soda, then with a solution of HCl, and finally with water. The zinc-copper battery (according to Gladstone

and Tribe) is obtained by means of copper which is deposited on the zincs in a powdered condition. For this purpose, a solution of copper sulphate is forced into P by means of pump O until the whole vessel is filled with it. The zinc plates are allowed to be in contact with the copper sulphate solution for twenty-four hours. The solution is then renewed, and this process repeated several times. The pile is now ready for use, and remains active for eighteen months or two years. The products to be purified are introduced by means of the tube E, and left in the vessel from six to forty-eight hours, the time varying with the amount of impurities and the temperature. We may here mention that under + 5° C the pile does not act, and above + 35° C a violent reaction takes place which destroys the copper coating.

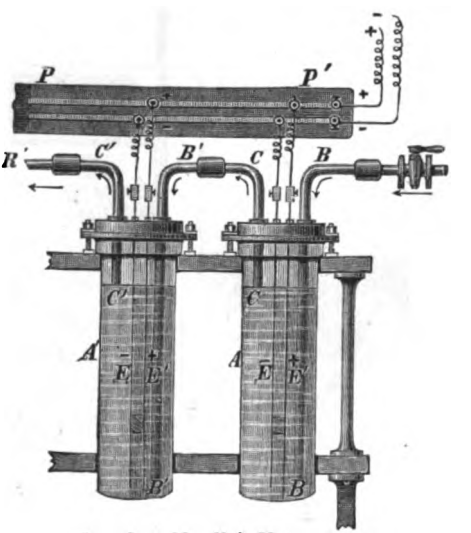


Fig. 567. – Naudin's Voltameters.

By the normal action a steady evolution of hydrogen and oxygen takes place during the decomposition of the water. The hydrogen hydrogenises the aldehyde, and deprives the products of their fusel oil, whilst the oxygen forms zinc oxide. In order to secure a uniform reaction throughout the vessel, the fluid is made to circulate through the tube F and the tube D by means of a pump. When this operation is finished the purified products are allowed to flow into the reservoir R by means of the tube H. Tube N indicates the height of the fluid in the vessel. During the process zinc oxide is formed, and is precipitated upon the plates in the form of a white powder, interrupting the reaction as soon as the action of precipitation has become sufficiently strong. To prevent this a little HCl is added to the products every eight days (5 kilogrammes of acid to 150 hectolitres of the liquid). The lid of the vessel has a hole in it through which the unused H is allowed to escape, and in order that the alcohol vapours which escape along with it may not be lost, a condenser is connected with the vessel. In most cases the above process is sufficient for the purification of the products of distillation, and they are then conveyed to the distilling apparatus. If the liquid still contains impurities it has to pass through a series of voltameters, where it is exposed to the effects of a powerful electric current. The voltameters consist of cylindrical glass vessels A A′ (Fig. 567), 125 millimetres in diameter, and 600 millimetres high, having ebonite lids through which the two tubes B C, B′ C′, and the electrodes + E, – E pass. The fluid circulates in the direction indicated by the arrows. Copper sheets are used at present for electrodes instead of platinum

electrodes. The small openings in the lid are closed by corks, and act as safety-valves in case the tubes become closed up.

The complete apparatus is shown in Fig. 568. The products of distillation flow from reservoir A into the vessels B, where the first hydrogenation takes place (the zinc plates are here arranged vertically). P_1 is the pump which causes the fluid to circulate. The fluid is then allowed to flow to vessels C, and from those, by means of the pump P, it is forced into the vessels D, where it is acidulated with $\frac{1}{1000}$ part of H_2SO_4. From here the fluid is brought to the voltameter F,

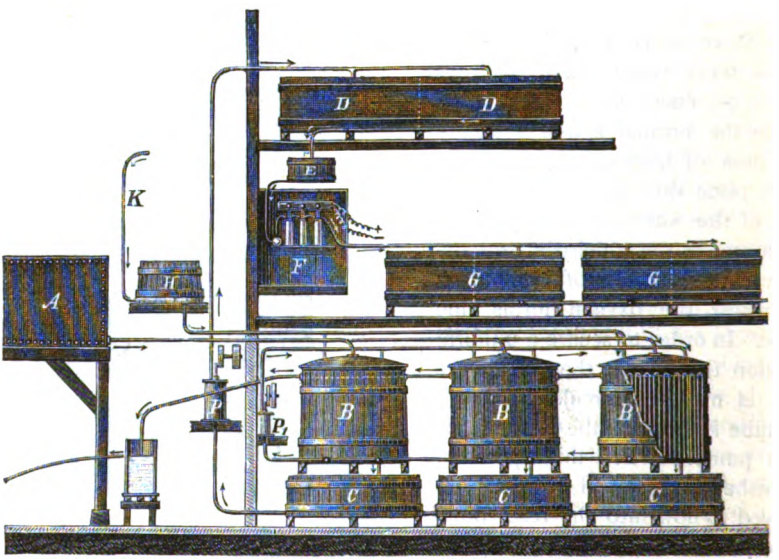


Fig. 568.—Naudin's Apparatus for Rectifying Alcohol.

but has to pass through a small vessel E, which regulates the supply by means of a cock which acts automatically. From the voltameter the fluid is conveyed to the vessels G, where it comes in contact with the zinc which absorbs the acid. The purified products are conveyed from here to the distilling columns, not given in the drawing. H is a reservoir for the copper sulphate solution, and K a tube for the conveying of steam to heat the liquids. The electric current is furnished at present by a Siemens machine, the magnets of which lie in a branch circuit. The current is regulated by means of resistance coils. A commutator allows of the insertion or exclusion of the voltameters in the circuit. The machine requires four horse-power. Naudin gives the following data regarding the cost of the old and new methods of purifying alcohols, assuming the alcohol to be obtained from maize: one hectolitre of purified alcohol by the old method costs 11·77 francs, one hectolitre purified by means of electricity costs 9·26

francs. It ought, however, to be added that alcohol obtained from certain raw materials cannot be completely purified by the old method at all.

We must not leave unnoticed the use of electrolysis for purposes of simple analysis. The facility with which the galvanic current separates out metals

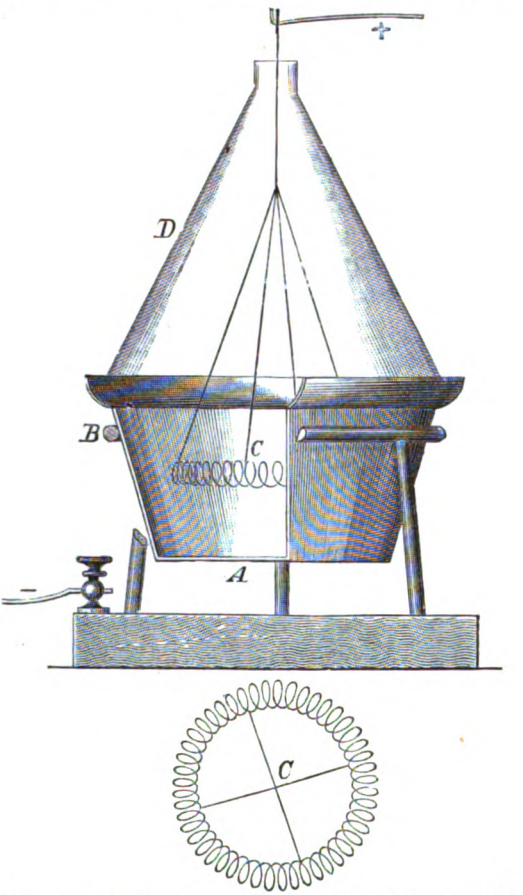


Fig. 569.—A Vessel for the Electrolytic Analysis of a Solution containing Copper.

from their solutions led to its use some time back for quantitative analysis. Gibbs and Luckow first determined copper quantitatively by this method. The determination of copper by electrolysis, although quite as exact as other methods, requires much less attention and labour. The forms of apparatus used for this purpose are all the same in principle, although varying in details, *i.e.* in all of them the electric current separates the copper at the negative electrode from the different solutions. Christophle used the apparatus shown in Fig. 569 for the determination of the copper in the bath for galvanotyping.

This consists of the platinum vessel A resting upon the metal tripod B, which is connected with the negative pole of the source of electricity. The platinum spiral C forms the positive pole. The glass funnel D is placed over the vessel A to prevent loss by spoiling, etc. Two elements joined in series, or a small Gramme machine, or a Clamond thermo-pile are used for the purpose. Not only may copper be precipitated by this method, but also other metals, such as

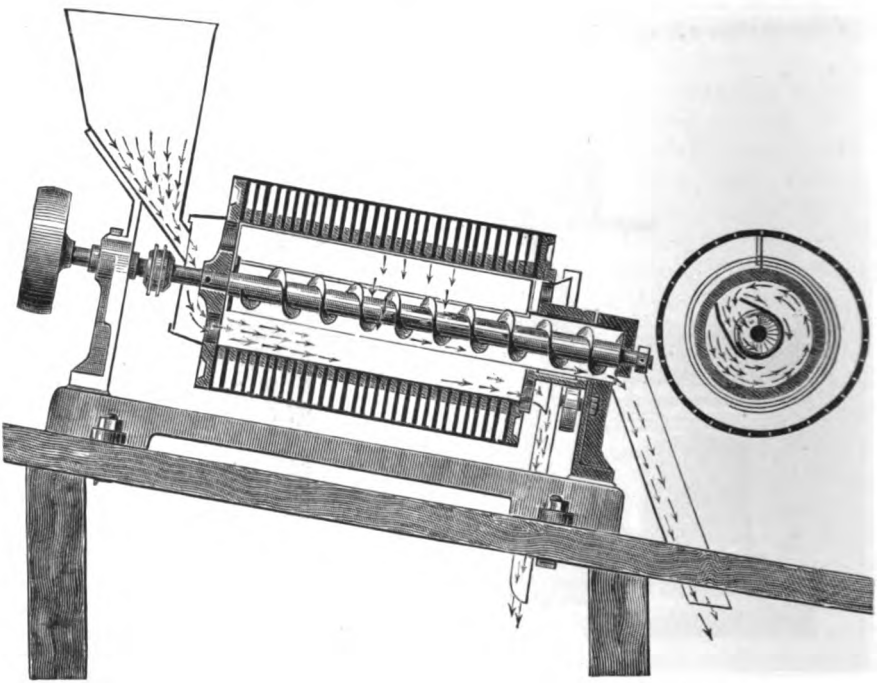


Fig. 570.—Siemens' Apparatus for the Separation of Metals.

nickel, cobalt, silver, mercury, etc. Cobalt and nickel, for instance, are not separated out by means of the electric current from an acidulated solution, although they are precipitated from an alkaline solution, hence they can thus easily be separated from copper. The copper is first separated out from the acidulated solution; the remainder is then made alkaline by adding ammonia, and then the cobalt and nickel are precipitated.

ELECTRO-METALLURGY.

The Separation of Iron Ores by means of Magnets.—Cases where magnetic ores have to be separated from non-magnetic ores occur frequently in practice, and for some time powerful magnets have been used for their separation.

Chenot and Froment (1852) constructed an electric ore-separator (*électro-trieuse*). Similar instruments have been constructed by Bavin, Siemens, Edison, Wassermann, and others. The ore-separator by Siemens is shown in Fig. 570. The rotation axis, which consists of steel, carries the driving gear and a brass spiral; the latter is surrounded by a brass cylinder which touches tangentially the inner walls of the drum. The drum consists of iron discs, separated from each other by small intervals, which are taken up by brass rings. The iron discs are connected with each other outside by means of iron bars. Before fixing

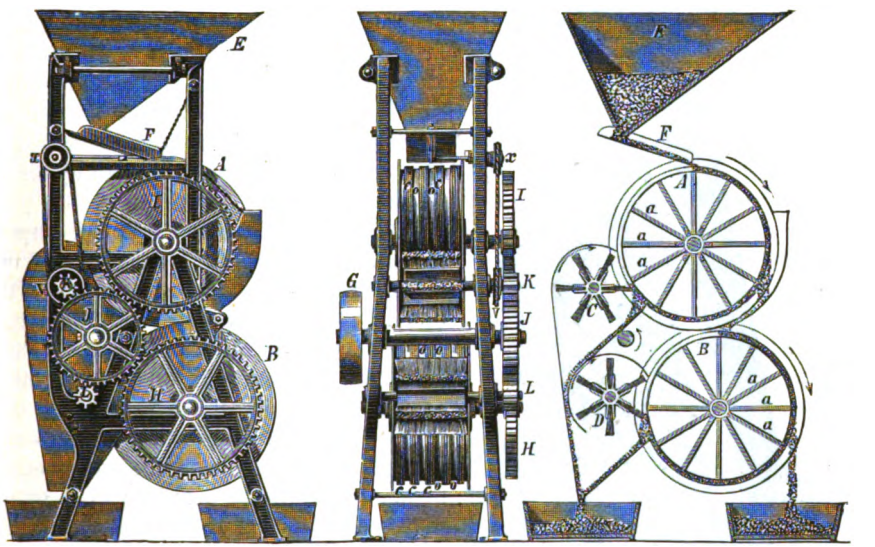


Fig. 571.—Bavin's Apparatus for the Separation of Metals.

the bars insulated wires are wound round the iron rings, so that when a current passes through the wires the iron becomes magnetised. The iron rings, together with the iron rods, form, therefore, peculiarly-shaped horse-shoe magnets, the poles of which are circular. The smooth inside of the drum represents a continuous series of north and south poles. When the apparatus is in use the axis, with its spiral and drum, rotates, whilst the brass cylinder remains fixed. The ores to be separated are introduced by means of a funnel into the apparatus, and fall upon the inside of the drum (the magnetic portions are indicated by the full arrows, the non-magnetic portions of the ore are indicated by the dotted lines). The magnet poles attract the magnetic portions of the ore, whilst the unmagnetic portions fall gradually to the lowest portion of the drum, and finally leave the apparatus. The portions sticking to the magnets are taken along with the drum, scraped off, and pushed by the rotating spiral through the brass cylinder. If all the poles of the ore-separator were equally

strong the ore would be attracted by the first poles. To prevent the overcrowding of the ores at these points, Siemens gives the first rings only a few turns of wire, increasing them as he goes on. The strength of current depends upon the nature of the ore, and has to be determined experimentally. The instrument is capable of separating twenty tons of ore per day. Siemens constructed this apparatus for a Belgian company, where Spanish zinc ores are utilised. The zinc ore called calamine or cadmia (carbonate of zinc) is usually found mixed with carbonate of iron, and is very difficult to separate. Formerly, during the whole of the process of roasting and calcination the iron had to be carried along with the zinc ore, causing a great expenditure of coal. A simple roasting is sufficient now to make the ore particles containing iron paramagnetic, and they can then be easily separated by means of the apparatus.

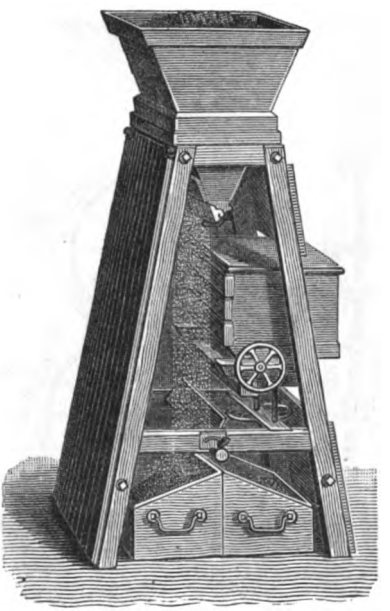


Fig. 572.—Edison's Apparatus for the Separation of Metals.

Bavin's apparatus for a similar purpose is shown in Fig. 571; it consists of two cylinders A and B arranged one above the other. The surfaces of these cylinders consist of protruding soft iron rings *c c c*, which are separated from each other by means of copper strips *o o o*. Each iron ring is connected with horse-shoe-formed magnets *a a a* in such a manner that one ring is magnetised by one pole, and the next ring to it by the other pole. C and D are rotating brushes that brush off the magnetised ore. The motion of the rotating portions is brought about by means of the belt-wheel G, which drives the toothed wheels J and I and H, as well as the wheel K and L connected with the brushes. The material is introduced through the funnel E, and falls upon the hopper F, which obtains its motion by a system of pulleys and ropes *x* and *v*. The upper cylinder possesses four, the lower cylinder five, iron rings; these are arranged next to each other in such a manner that the iron rings of the lower cylinder are opposite the copper strips of the upper, and *vice versâ*. The magnetised particles then that have not been attracted by the upper cylinder are sure to be attracted by the lower cylinder. Of the magnets which magnetise the iron rings there are fifteen in the upper and twenty in the lower cylinder, each having an attraction of five kilogrammes.

Edison's magnetic-ore separator, shown in Fig. 572, is distinguished by its great simplicity. Instead of allowing the ore to come in contact with the magnets, the magnets are arranged so as to act at a distance. The particles

containing iron on their way to the bottom of the apparatus are attracted by powerful magnets, in order to pass which they have to deviate from their original direction. The box to the right of the drawing covers the magnets.

In preparing the clay for the making of porcelain, electro-magnets have been resorted to. To obtain perfectly white porcelain, it is necessary that the material should be free from iron. Pilliduyt and Sons remove the iron by using magnets. The solution is allowed to pass between the poles of a magnet, which retain the particles of iron. The apparatus used is capable of purifying from 500 to 600 kilogrammes of material daily; it was found that 12 kilogrammes of porcelain clay contained about one gramme of iron. The apparatus is cleaned twice a day by simply cutting off the current and forcing water with considerable pressure through the tubes near the magnets.

The Use of the Current in the Mercurial Process of Separating Gold and Silver.—The usual method of obtaining gold or silver from ores which contain them, is to powder the whole and then treat with mercury; an amalgam of the metal is formed, from which the pure metal is obtained by distilling off the mercury. This method answers very well if there be no compounds of sulphur in the ore; the presence of these compounds making the mercury impure and destroying its bright surface, prevents the particles of gold from mixing with it. Guerout mentions, for instance, that with an ore containing 1,250 grammes of gold per ton, the gold could not be extracted from the sulphurous ore by means of mercury, as the expense would be comparatively too high. Several methods of cleaning the mercury have been proposed, such as adding sodium, or a stream of chromic acid, etc., but these methods have practically proved of no avail. Richard Barker, by employing the electric current, has at last obtained the desired result. He observed that when mercury is connected with the negative pole of a source of electricity, and the water flowing over it with the positive pole, any impurities contained by the mercury are driven away from the negative pole to the positive pole (*i.e.* the water anode), giving to the mercury its bright surface again. On these principles Barker took out a patent for his *electric process of obtaining gold and silver from ores.* The ore, powdered and diluted with water, flows over the slightly inclined plane A A (Fig. 573), passing the mercury contained in the troughs *a a*, the bright surface of which retains the particles of gold, whilst the other compounds are allowed to flow off with the water. To retain the bright surface of the mercury, Barker connects the troughs containing it with the negative pole of an electric machine, so that the mercury becomes the kathode. The positive pole of the machine is connected with the water, making it the anode. The current coming from the negative pole of the machine flows through the wire *m* into the mercury trough 1, from it through the connecting wire *m* to the mercury trough 2, and so on. The conveying of the positive current for troughs 1, 2, 3 is shown in Fig. 574. Four metal bars *s* are fastened parallel to the axis of the shaft upon a wooden shaft, set in motion by means of the pulley C and string. These bars are held in position by rings placed at

the ends, and in the middle of the shaft. To these metal bars, metal wires *e* are fastened radially, the length of which is so measured that during the rotation of the shaft their ends dip into the water, but do not touch the surface of the mercury. The contact pin v, connected with the positive pole of the machine, slides upon the disc opposite to c; by this arrangement the metal bars and the projecting wires become anodes. Pieces of wood *r* are fastened to the wooden portions of the shaft between the metal bars in a way similar to that in which

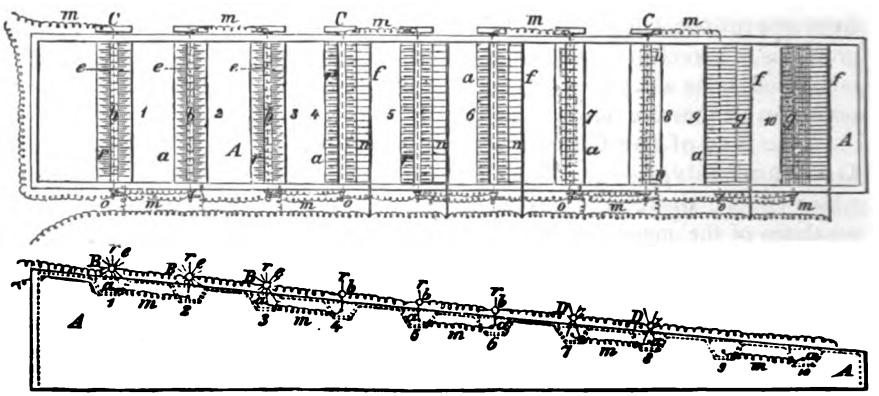


Fig. 573.—Separation of Gold.

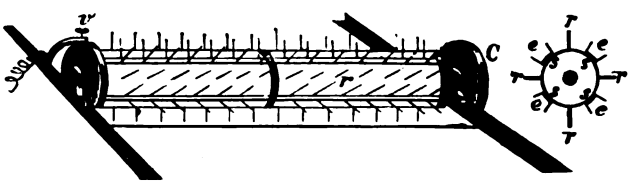


Fig. 574.—The Stirrers.

the wires are attached; but the former are longer than the latter, and therefore dip into the mercury during the rotation of the shaft, keeping the mercury well stirred, and thus facilitating amalgamation.

The shafts *b* (Fig. 573) are used over the mercury troughs 4, 5, and 6, with their pieces of wood *r* only as stirrers; the positive current is not conveyed through the shafts as before, but through the wires *n*, which dip into the water, and are fastened to the metal rods *f*. The troughs 7 and 8 have no stirrers, and their current passes through the metal pin *s*, fastened to the shaft D. This arrangement, as may be seen from the drawing, only allows the current to pass twice for every full revolution of the shaft; as the troughs 9 and 10 have no shafts at all, the current is conveyed by means of the metal wires *g*, which are fastened to the metal rods *f*. It is said that satisfactory results have been obtained by means of this process.

Electro-Smelting.—The heating effects of the galvanic current have also been utilised for metallurgy. To obtain a high temperature, two methods have been employed, viz. the oxyhydrogen blow-pipe and the regenerating furnace. The voltaic arc, however, produces a temperature which considerably exceeds that obtained by the former method, and Siemens has used it in an apparatus by means of which refractory metals may be fused. T (Fig. 575) is a crucible consisting of graphite, or another similar substance not easily fusible. H serves as a kind of jacket, containing pieces of charcoal, or a similar substance that conducts heat badly. There is a hole in the bottom of T, through which an iron, platinum, or carbon rod passes. There is also a hole in the lid of the crucible, through which the negative electrode passes. The negative pole, consisting of pressed carbon of considerable dimensions, is suspended, by means of a copper strip at A, from the beam A B; to the end B is fastened a hollow cylinder of soft iron, which moves freely inside the spiral S, which has a resistance of about 50 ohms. The attracting force of S may be balanced by means of a weight. One end of the spiral is connected with the positive, the other end with the negative, pole of the arc. The resistance of the arc may, therefore, be adjusted as required by sliding the weight *q* along the beam. If the resistance in the arc is increased by any cause, the current passing through the coil also increases, and the force of attraction overcomes the counterweight, causing the negative electrode to dip deeper into the crucible. If the resistance in the arc diminishes, the weight forces the cylinder back into the spiral, lengthening the arc until equilibrium is restored between the acting forces. Besides the automatic regulation of the arc, it is of importance for the success of the smelting that the metal to be fused should form the positive pole, as here the highest temperature is obtained. William Siemens melted one pound of filings in an apparatus similar to the one here described in thirteen minutes; the crucible had a depth of 20 centimetres, and the current used could supply a light equal to 6,000 normal candles.

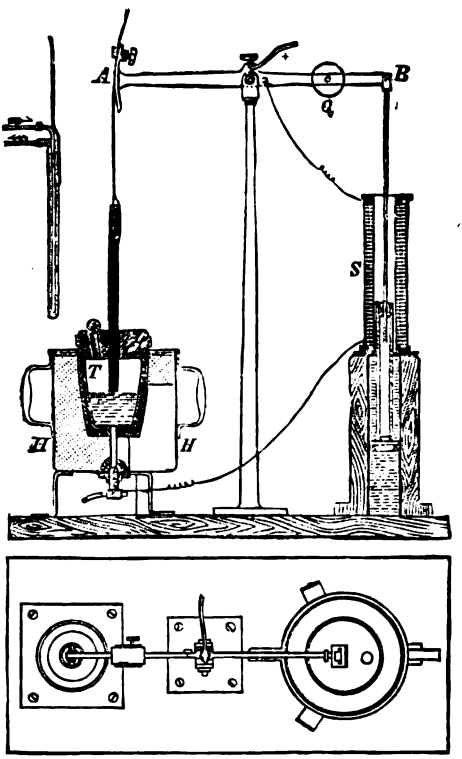


Fig. 575.—Siemens' Electro-Smelting Apparatus.

When a carbon rod is used as the negative pole, the metal to be fused might undergo a chemical change; if this is to be avoided, the negative electrode must consist of a substance that causes no change. Siemens uses a so-called water pole for this purpose, *i.e.* a tube of copper through which water is allowed to circulate (drawn in the figure separately). As regards the expenses of electric melting, Siemens found that by using a dynamo-electric machine, driven by a steam engine, one pound of coal could melt nearly one pound of cast steel. The following points show the advantages of this process: (1) theoretically the temperature obtainable is unlimited; (2) the fusing takes place in a perfectly neutral atmosphere; (3) the process needs no lengthy preparations, and can be conducted under the eyes of the operator; (4) by using ordinary materials difficult to fuse, the degree of heat practically obtainable is very high, as in the electric crucible the fusing material has a higher temperature than the crucible itself; whilst by the ordinary method the temperature of the crucible surpasses that of the melting material.

Uses of Electricity in the Separation of Metals.—Electricity is far more extensively employed for the separation of metals than for the purposes just now described. Siemens and Halske have for some time paid particular attention to this branch of industry, and have constructed special machines for the purpose. By the Refiners' Trading Company, Hamburg, six Gramme machines are used. The main object of this establishment is to produce copper of almost absolute purity (for instance, analyses of the metal produced gave 99·95 per cent. of copper). The royal metals contained in the copper are also obtained in a separate state, so that they can be utilised. Alloys containing copper and silver are directly separated into copper and silver. The copper obtained from German coins during the year 1877—1878 amounted to 115,000 kilogrammes, the silver to 33 kilogrammes, and gold to 23·5 kilogrammes. The daily production of copper during twenty-four hours in 1881 was 1,600 kilogrammes. The electric purification of copper which has already passed the refining furnace, and contains only about 2 per cent. of impurities, is perhaps the simplest method of obtaining the pure metal on a large scale. Siemens gives the following description of the method:—The machines c (Fig. 261) and c_2 are specially adapted for this case, and the former is capable of separating out 6 centimetres, the second 3 centimetres of pure copper in twenty-four hours, from twelve baths joined in series. c_1 requires 10, c_2 5 horse-power. The surface of the electrode of each bath must have 30 square metres; for instance, thirty plates of raw material having an area of 0·5 × 2 metres will be required, and as many plates of pure copper. The cross section of the leads has to be 20 square centimetres. Machines may be constructed for every kind of metal separation by the electric current. To construct machines larger than c_1 is disadvantageous from many causes; it is, therefore, better to use several machines. When the raw material contains other metals besides copper, greater energy is required in proportion to the impurity of the raw material. Most energy is required when the material does not consist of impure metal, but

has to be separated from a solution. In this case for kathodes we must use carbon, platinum, lead, or other substances which do not easily oxidise. To obtain the silver from lead, Keith casts thin plates of the lead, covers them with muslin, and uses these as anodes in a decomposition cell which contains lead sulphate and sodium acetate in solution (70 to 85 grammes of lead sulphate to 780 grammes of sodium acetate). For kathodes lead plates are used. The lead crystallises out at the kathode, whilst in the sack surrounding the anode silver and the other metals are retained. The solution must be constantly stirred, in order to prevent polarisation.

Ores containing Sulphur.—Not only are impure metals purified by means of the electric current, but metals have been directly separated from their ores. Blas and Miest took out a patent for their method of obtaining metals from ores containing sulphur. If the same metal as that contained in the bath is used as an anode, the metal contained in the bath will separate out at the kathode, and the sulphur will be thrown down at the anode. Ores containing antimony and arsenic also yield these up at the anode, but mostly in the form of oxides, which may easily be separated by means of the current. Blas and Miest break the ore in pieces first (such as copper pyrites, etc.), and then press it into moulds made of steel, under a pressure of 100 atmospheres, first cold and then at 600°. The plates, when cool, are fastened to iron rods and hung in the bath, and are then connected with the positive pole of a machine. If the ore happens to be zinc sulphide, the bath consists of zinc sulphate, nitrate, or chloride. A metal not soluble forms the kathode.

Aluminium and the Allied Metals.—Bunsen succeeded in obtaining aluminium by electrolysis from the double salts, sodium chloride and aluminium chloride, as has been already mentioned. The separation, however, is somewhat difficult, and requires a careful regulation of the temperature. Ordinarily the aluminium is obtained by decomposing the double salt mentioned with sodium. The price of aluminium depends upon the cost of sodium, of which one kilogramme usually costs about 40 francs. According to the *Bulletin de la Compagnie Internationale des Téléphones*, a method has been discovered for producing sodium which would make the price of one kilogramme only 1 franc. As aluminium compounds are greatly distributed over the surface of the earth, and this metal is of great value for many technical purposes, the reduced price of from 10 to 20 francs per kilogramme, instead of 300 francs, as at present, would cause it to be largely used.

Graetzel has also taken out a patent for obtaining aluminium, magnesium, and all the alkaline metals. The principle of his method is that by means of a proper apparatus the kathode is exposed to the influences of a reducing gas, and protected from the gases that are evolved at the anode. The apparatus shown in Fig. 576 is especially intended for obtaining aluminium. It consists of a crucible *g*, which has a metal vessel *b*, serving as a kathode. The crucible, which is made of fire-clay, or some similar substance, is protected from the direct flame by the jacket *h*; with graphite crucibles, this jacket is

not needed. The crucible is closed by a lid of the same substance, which has an opening for the vessel *e*, and also openings for the tubes *a a'*. The vessel *e* (drawn separately in the figure) consists of porcelain, having a lid at the top, which has a piece of carbon *c* as an anode. The tube *f* of this vessel conveys away the gases evolved at the anode. The opening at the lower portion allows of the circulation of the molten salt (aluminium chloride). A reducing gas is introduced through the tube *a*, and again escapes at *a'*. In the vessel *e* are also placed the rods *d*, consisting of equal portions of clay and carbon; for obtaining magnesium, *d* consists of magnesia and carbon. The carbon unites with the oxygen of the clay, and the aluminium with the chlorine

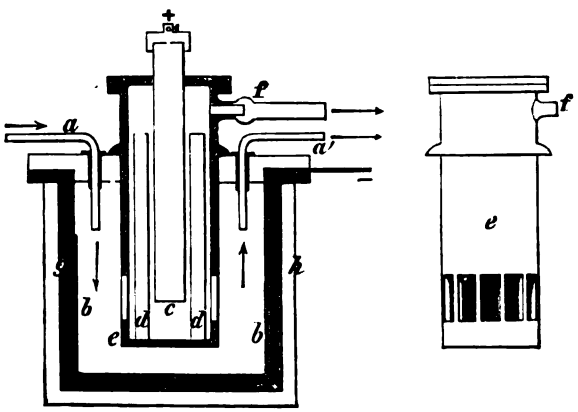


Fig. 576.—Apparatus for the Separation of Aluminium.

evolved at the anode. The aluminium chloride produced in this manner unites with the molten mass. Several of these pieces of apparatus may be united, having the same tubes for the passage of the gases. The production of magnesia for use in the separation of aluminium is carried out on a large scale, but several difficulties have still to be overcome.

ELECTRO (OR GALVANOPLASTIC) DEPOSITION.

Here we distinguish between two distinct branches: the making of objects that are coated with a thin metal layer comes under the head of electro-plating, and that of objects forming copies of others comes under the head of electro-typing (called by the Germans *galvanoplastic* and *galvanostegie*). The sources of electricity used for both branches of electro-deposition are, as a rule, galvanic elements, thermo-piles, or electric machines. Only those elements can be employed that furnish a constant current, such as Daniell, Meidinger, Bunsen, Grove, Smee, etc. Thermo-piles are very useful, but are too expensive, and furnish only a weak current. In large establishments machines are mostly used.

For electro-deposition, and all kinds of electrolysis, currents of small potential (so-called quantity currents) are required; therefore, when elements are used, the plates must be large, or else a number of small-plated elements have to be joined parallel.

Machines for Electro-Plating.—If machines are used they have to be constructed with small internal resistance. Such machines are constructed by Gramme, Schuckert, Siemens, and Ferraris on the Continent, and in England by Elmore, Paterson and Cooper, Oppermann, and others. The machines of Siemens and Schuckert have already been described. The machine by Gramme (Fig. 577) is easily distinguished from the ordinary model, page 252, for it has double the number of electro-magnets, and therefore four independent poles, of which every two have the same polarity: one of the couples is united by the upper, the other couple by the lower shoe. The iron cores of these electro-magnets possess a diameter of 120 millimetres, by a length of 410 millimetres; round each of these a copper sheet of 1·1 millimetre in thickness is wound thirty-two times. The resistance in these electro-magnets is, therefore, 0·0012 ohm, when joined in series; when the eight magnets are joined in two groups the resistance is 0·00028 ohm. The shoes of the electro-magnets surround a ring of peculiar construction. This ring has a diameter of 365 millimetres, and a length of 442 millimetres. It consists of forty divisions, of which twenty are connected with the sectors of the right-handed commutator, and twenty with the sectors of the left-handed commutator. Each coil consists of seven copper bands of 2·8 millimetres in thickness, and 10 millimetres in breadth, which are insulated from each other by intervals of air. Every two succeeding coils form a division of the ring. The resistance of the armature when the two portions are joined in series is 0·0004 ohm, and sinks to 0·0001 ohm when they are joined parallel. When joined in series a current of 8 volts is obtained by 500 revolutions per minute, when joined parallel the E. M. F. is equal to 4 volts. The resistance of all the copper turns, when joined parallel, is equal to 0·00038 ohm. The machine has four brushes corresponding to the two commutators; each of these brushes is double, and each double brush has a contact surface of 24 square centimetres. The machine weighs 2,500 kilogrammes, of which the copper weighs 735. By 15 horse-power, 1,000 kilogrammes of copper can be deposited per day.

Arrangements for Preventing a Reversion of the Poles.—With electrolytic baths care has to be taken to prevent changes of the polarisation of the electrodes. During the starting of a dynamo-electric machine, the generation of current, as we know, is brought about by the weak residual magnetism of the iron cores. The direction of the currents depends upon the polarity caused by the residual magnetism. When the machine stops the generation of current ceases, and the current produced by the polarisation of the electrodes can flow into the coils of the machine. Now this polarisation current, as we have seen, flows in the opposite direction to the primary current; hence, flowing through the coils of the magnets, it may reverse their polarity. If then the

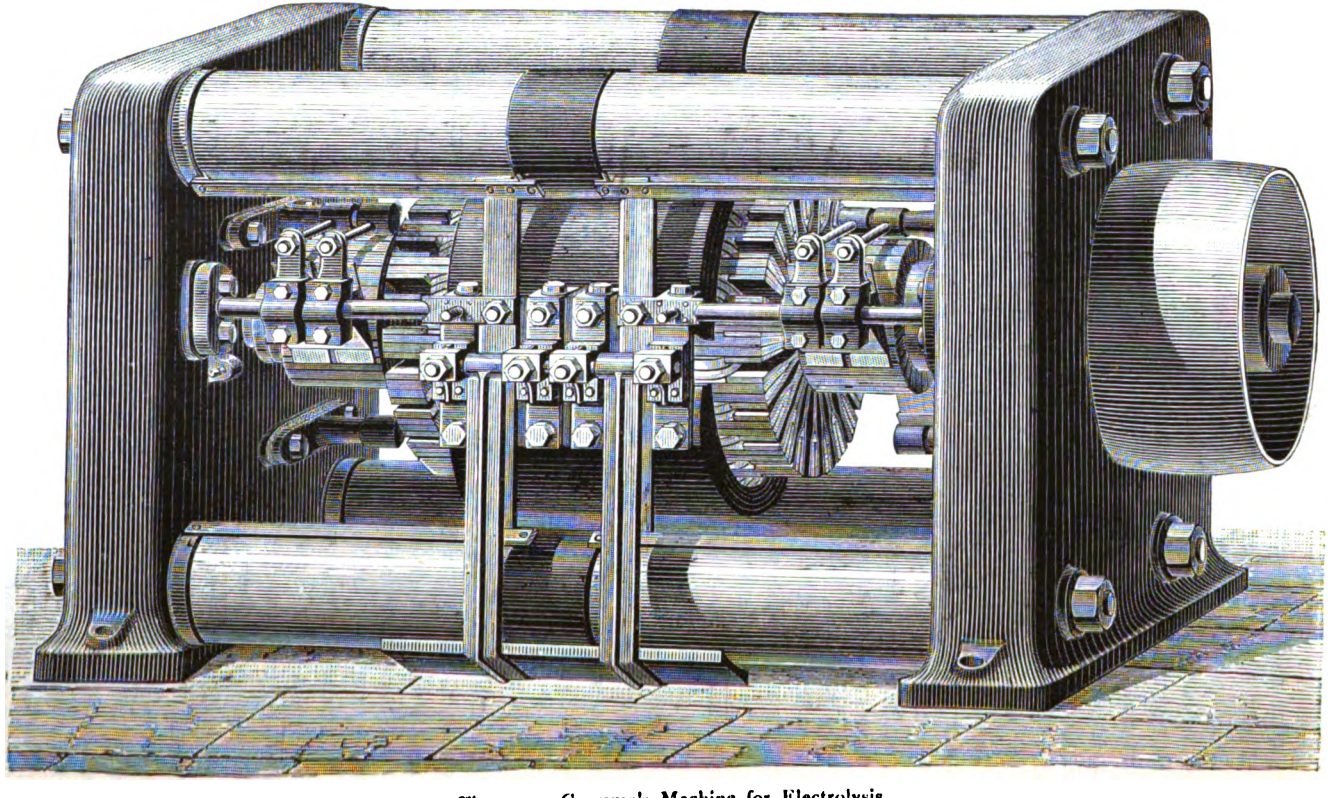


Fig. 577.—Gramme's Machine for Electrolysis.

machine is set in motion again, the poles are changed, making the anode of the bath a kathode, and the kathode an anode. The current will now dissolve the metal at that place where it was deposited before. A reversion of the poles may thus take place at every stoppage of a dynamo-electric machine, and, indeed, if polarisation is very strong, reversion of the poles may take place even when slackening the speed. During the normal speed of a machine change of polarity will be impossible, as only such machines are used as are capable of furnishing currents suitable for the purposes for which they are required.

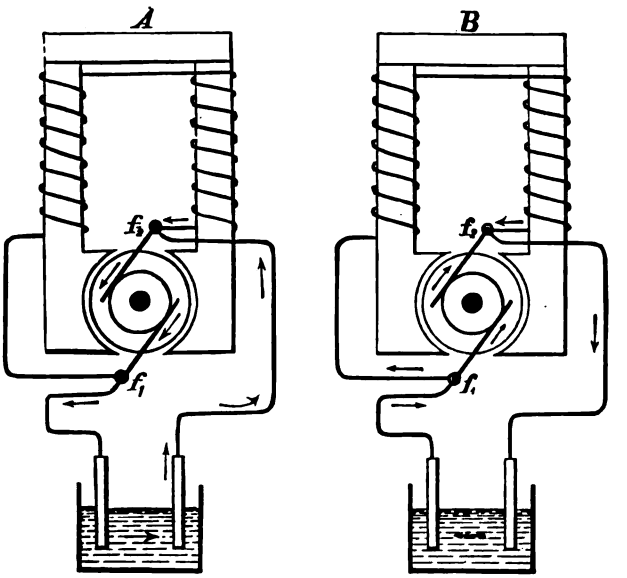


Fig. 578.—Arrangements for Neutralising Polarisation Currents.

There are three ways of preventing this undesirable change of polarity: (1) by making the magnets independent of the circuit of the decomposition cells; (2) by having the magnets in a branch circuit; (3) by using a current-breaker. The magnets are independent of the circuit of the decomposition cells when machines with permanent steel magnets are used, or when a small generating machine is used for the electro-magnets; or, lastly, when a portion of the armature coils is exclusively connected with the coils of the electro-magnets. Gramme adopted this principle in the construction of his first machines, and it is still adopted by Schuckert, Fein, and others, by means of a double ring and two commutators. A separate machine for the electro-magnets would only be economical for large installations. When the magnets are in a branch circuit the reversion of the poles by the polarisation current cannot take place; this may easily be seen from Fig. 578. In A the current coming from the armature

separates at f_1; one branch flows to the bath, the other to the coils of the electro-magnet; the two branches unite again at f_2. In B the polarisation current, which has the opposite direction to the current of the machine, flows to f_1, branches off here, and the two branches unite again at f_2. In both A and B the current flows in the same direction through the coils of the arms of the electro-magnets. Gramme prevents the change of poles by the insertion of a current-breaker. This consists of an electro-magnet inserted in the circuit, the armature of which, when attracted, makes contact in the circuit. If the machine stops from any cause the armature falls off, and breaks contact between the machine and the decomposition cell. The polarisation current, therefore, will not be able to enter the electro-magnets, and cannot alter their polarity.

A machine by Weston is much used for electro-decomposition in America. Fig. 579 shows the complete machine H, with its current-breaker *c*, and Fig. 580 gives the details of construction. The machine consists of a cast-iron case to the inside of which are fastened six magnets *r* (Fig. 580 B), which form the inducing magnets of the machine; their coils are connected and so arranged that when a current flows through them, the poles become alternately south and north. Fig. 580 A shows one of the magnets. The hollow iron core *e e* is surrounded by steel plates *s s*, and round these the wire is coiled. The iron cores are hollow, for conveying water through the magnets for cooling purposes, and they have steel plates, which become permanent magnets, to make the reversion of poles more difficult. The armature consists of six electro-magnets r^1, which are fastened to the shaft of the machine; they are coiled in a similar manner to the inducing magnets, and are connected in couples. Although currents of opposite direction are induced in the coils owing to the particular mode of coiling, and the use of a commutator, consisting of six segments H, the alternating currents are converted into continuous currents. The current-breaker (C, Figs. 579 and 580) consists of a circular disc *s*, which rotates round a horizontal axis; *g g* are sliding pieces, which can move in *a a*. When *s* is at rest the sliding pieces are pressed against the rotation axis by means of spiral springs, regulated by the screws *r r*, thus making contact. The contact is not made when the disc rotates rapidly, because the two sliding pieces *s s* are forced away from the axis by the centrifugal force. The current-breaker is made to rotate by means of the driving belt *u*. The pole-clamps of the machine are connected with the current-breaker and the electrodes of the bath. As long as the machine has the proper speed, there is no other way

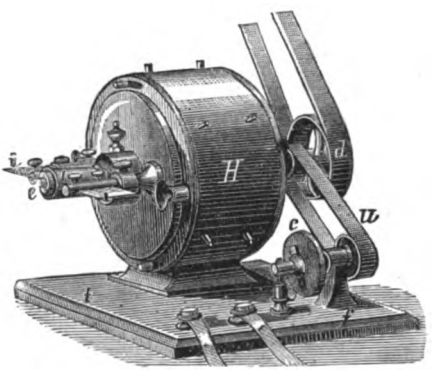


Fig. 579.—The Weston Machine for Electrolysis.

for the current than that through the bath; when the machine stops, or diminishes its speed considerably, the sliding pieces are pressed against the axis, and contact is made. The polarisation current coming from the bath has now two ways open to it, viz., through the machine, and through the short circuit of the current-breaker; as the latter offers little or no resistance, the current will pass by this channel; but even if a branch current should flow into the coils of the magnets, this current would be so weak that it would not be capable of reversing the polarity of the magnets.

The conduction of the current is, as a rule, very simple, as the sources of electricity are generally at a short distance from the deposition cells; copper wires

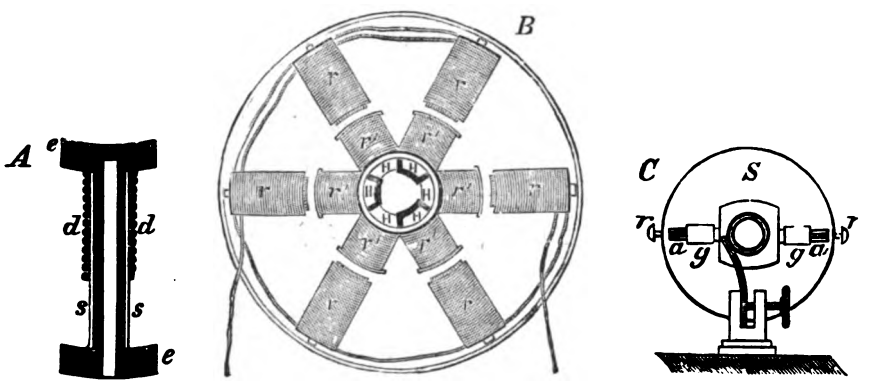


Fig. 580.—The Weston Machine and Commutator.

are usually taken on account of the small resistance; it is best to solder the different joints, but where this is impracticable mercury cups or clamps are used. The strength of current depends upon the nature of the bath; well-conducting baths require a less powerful current than badly-conducting ones, such as alkaline baths, for instance. It follows from Ohm's law that the galvanic current has its maximum effect when the inner resistance is equal to the outer resistance; it is, however, well in practice to make the inner resistance about three-eighths of the outer; as, by using galvanic batteries, the strength of current does not remain constant, and has to be either increased or diminished during work. At the commencement of every operation for electro-deposition weak currents ought to be used, to allow the particles time to thoroughly cover the surface; after the first layer has been deposited a stronger current may be used to hasten the process. It is, therefore, necessary to use a galvanometer and a resistance arrangement; for the latter the simple apparatus shown in Fig. 581 may be used; it consists of a board having German silver wire wound round contact pins; by means of the slider the current may be broken, or resistance may be inserted or taken out.

Fig. 582 represents an apparatus in which the source of electricity and depositing cell are in one. A glass cylinder, open at both ends, is supported, as shown in the figure; bladder, parchment, or a similar substance is tied round the bottom of the cylinder. In the place of this inner glass vessel, with its

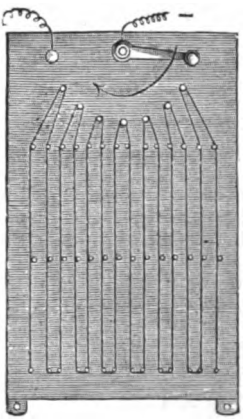


Fig. 581.—Rheostat or Frame Resistances.

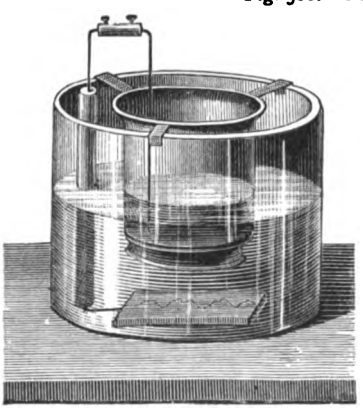


Fig. 582.—Galvanoplastic Apparatus.

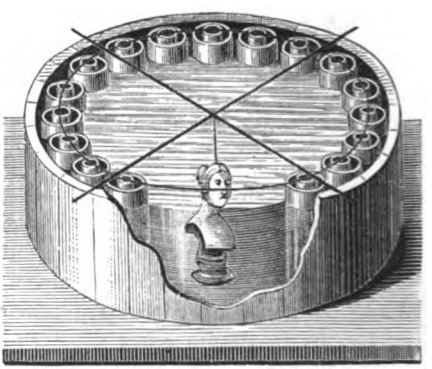


Fig. 583.—Galvanoplastic Apparatus.

porous bottom, a diaphragm may be used, as in galvanic elements. In the inner vessel is a zinc plate, and the object to be plated is connected with the wire of the outer vessel. The outer wire has a non-conducting substance covering it, such as wax, gutta-percha, glass, etc. The two wires are connected by means of a clamp. The inner vessel contains dilute sulphuric acid, the outer, if copper is to be separated out, a concentrated solution of copper sulphate. This apparatus, of course, can only be used for copper deposits of small objects, and then only for such objects as show no considerable cavities or protuberances, and require the deposit only on one side.

By means of the apparatus of Fig. 583, which is at the same time a bath and a battery, different objects may be coated with copper; a number of porous cells are placed along the sides of the outer vessel containing, for instance, copper sulphate solution; each of these porous cells has a zinc cylinder, surrounded by dilute sulphuric acid. A circular wire connects all the zincs, and is also connected with the crossed wires that carry the objects.

The source of electricity and the deposition apparatus are, however, always separate when electro-plating is carried on upon a large scale. The galvanoplastic apparatus, as a rule, consists of some kind of earthenware that will with-

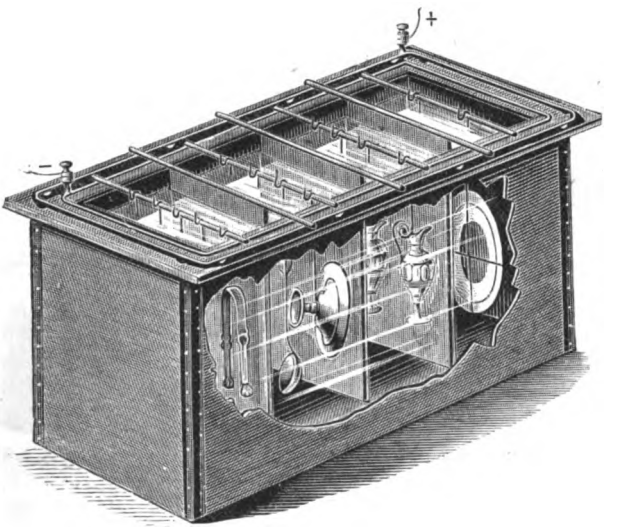


Fig. 584.—Galvanoplastic Bath.

stand the effects of acid, or of wood, lined with gutta-percha, as shown in Fig. 584. Two wires, parallel to each other, are fastened upon the edge. The outer wire frame, which lies higher than the inner, has the positive clamp; while to the inner lower wire the negative clamp of the bath is fastened. The metal plates—silver plates, for instance—are hung at a distance of 1 to 2 feet from each other; the cross-bars to which they are fastened rest upon the outer wire frame; shorter cross-bars are placed between the silver plates, from which the objects to be silver-plated are suspended.

The Process of Electro-Plating.—First it is necessary that the object to be plated be scrupulously clean, so that no chemical compounds may be formed between the metallic deposit and the object. The cleaning of the surface may be brought about in either a mechanical or chemical way. Smaller objects are cleaned by means of stiff brushes, using either fine sand or pumice-stone, with soap and water. For larger objects metal brushes are used, and

a decoction of the root of the *Saponaria officinalis*. Some forms of these brushes are shown in Fig. 585. Cleaning in a chemical way is brought about by mordants; larger objects are immersed in the liquid; smaller objects are placed in sieves consisting of materials that will resist the mordants, shown in Fig. 586. The mixture of acids, or "brine," as it is technically called (in German, *Brenne;* from *brennen*, to burn), is intended to remove all manner of impurities, such as fats, layers of oxide, etc., without injuring the object itself. Sulphuric acid, for instance, would form with lead, or alloys of lead, a white insoluble salt—lead sulphate. Nitric acid with zinc, or alloys of zinc, would form zinc oxide, etc. The acids, then, which are to be used for cleaning have to be selected according to the nature of the object to be cleaned. In cleaning brass sheets, for instance, dilute sulphuric acid is first used in order to get rid of the dark coating of copper oxide; the sheets are then well washed

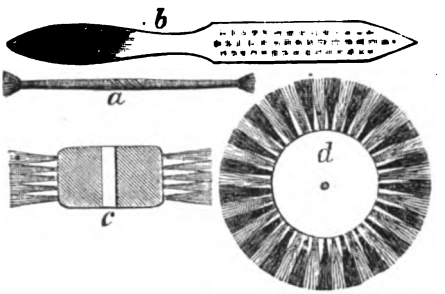


Fig. 585.—Electro-Platers' Brushes.

Fig. 586.—Sieve.

with water and placed in concentrated nitric acid, or a mixture containing nitric and sulphuric acids; to this mixture organic matter, such as sawdust, soot, snuff, etc., is frequently added.

Copper-Plating.—The metals usually coated with copper are: iron, zinc, and sometimes tin; as zinc and iron separate out the copper from acid solutions without the current, it is necessary to use alkaline solutions for the baths; such, for instance, as a mixture of copper cyanide (consisting of copper and cyanogen or prussic acid) or potassium cyanide and water. For tin, cast iron, and large objects of zinc, Roseleur gives the following mixture: Sulphuret of sodium, potassium cyanide, copper acetate, ammonia, and water. To avoid the poisonous compounds of cyanogen, Weyl recommends the following for the coppering of cast iron, rod or bar iron, and steel: Copper sulphate, 350 grammes; sodium or potassium tartrate, 1,500 grammes; caustic soda, 800 grammes; and water, 10 litres. The vessel to hold the fluid may consist of earthenware or wood, lined with gutta-percha, etc. The objects to be coppered are hung from thin copper wires forming kathodes; from three to twenty-four are put in at once, as may be required. When taken out the objects are treated with

water and a brush; they are then dried in sawdust, and placed in a room, the temperature of which is about 50 degrees.

To deposit brass or bronze, Jacobi and Walker give the following process: A copper plate immersed in a concentrated potassium cyanide solution is connected with the positive pole of a Daniell two-cell battery; a second plate consisting of another metal is connected with the negative pole of the battery: copper is first dissolved in the potassium cyanide solution; when the solution is saturated with it, copper is deposited at the other plate (the trial plate). As soon as this reaction takes place the copper plate is replaced by a zinc plate, and the latter is left long enough under the influence of the current for brass to separate out at the trial plate. The brass bath is now ready, and instead of the trial plates, the objects to be coated with brass are immersed. A zinc and a copper plate have to be used when iron has to be coated with brass. Morris and Johnson use the following mixture: Ammonium carbonate, 16 parts; potassium cyanide, 16 parts; copper cyanide, 2 parts; zinc cyanide, 1 part; and water, 160 parts. This bath is used both hot and cold. If objects are to be coated with bronze in a similar way, tin is used instead of zinc.

Gold-Plating.—The gold bath is usually prepared by dissolving 45 grammes of potassium cyanide in 1 litre of water, to which gold chloride is added; to make the bath alkaline, ammonia is added; it may be used cold, but when used hot the colour is somewhat improved, and the coating is more durable. The concentration of the solution, the shape and position of the gold anode in relation to the object, as well as the strength of current, have to be carefully studied. For partial gilding or silvering, the portions which are to appear in gold or silver are coated with white lead first, whilst the remaining parts are varnished. The whole object is then immersed as positive pole in a bath of dilute nitric acid. The object is then taken out, well washed, and placed as negative electrode in a silver or gold bath.

Silvering.—Objects which have to be coated first with copper, as steel, zinc, tin, etc., are brought directly from the copper bath to the silver bath. With objects of other metals, a mercury bath is first used, which is prepared by dissolving mercuric nitrate in water; sulphuric acid is added to this solution until it becomes clear again. The objects remain in this mercury bath until they have a white coating, and are then brought to the silver bath, where they receive a thin coating. They are then treated with the brush, and again brought to the silver bath. Silver-plated objects, as a rule, show at first very dull surfaces; the polish is given to them by a burnisher or brush. To prevent the formation of marks and irregularities, owing to the motions in the fluid, the objects are sometimes kept moving by clockwork. In the establishment of Messrs. Elkington, it was discovered that by adding carbon sulphide to the silver bath, the objects came out of it with a bright surface, making the polishing unnecessary, and thus producing cheaper articles. The silver bath is prepared from 1 kilogramme of potassium cyanide, 120 grammes of silver cyanide, 9 litres of water, and 75 grains of carbon sulphide.

If objects are to be coated with gold or silver, it is necessary to know the weight of the coating; for this purpose Roseleur devised the apparatus shown in Fig. 587. The beam of a sensitive balance has at one end a tin pan s, at the other end the metal rim R, from which are suspended the objects dipping in the bath B; *m* is a metal pin that dips into a mercury cup *n*, which is connected with the negative pole of the battery, the positive pole being connected with the anode

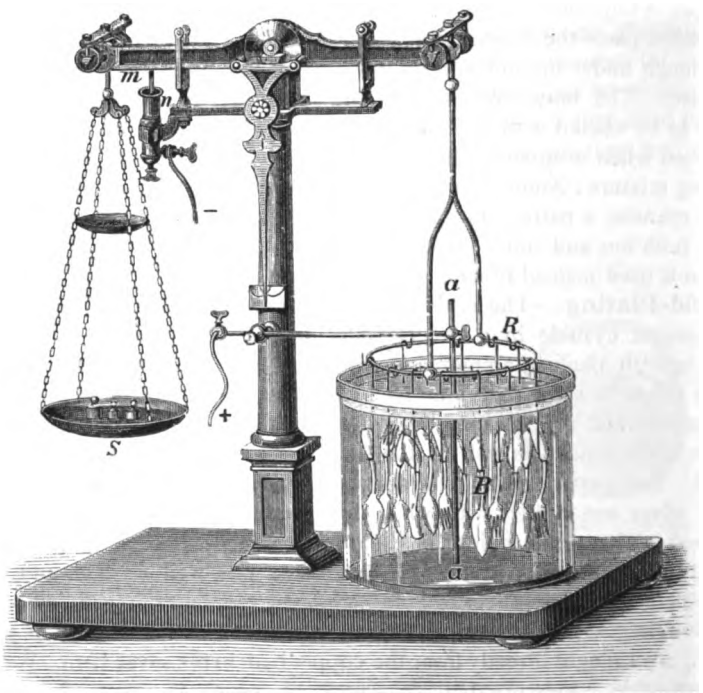


Fig. 587.—Roseleur's Plating Balance.

a (drawn in the figure as a simple rod). After the objects have been fastened to R, their weight is counterbalanced. The metal pin will not at first dip into *n*. Weights equal to the weight of the metal to be deposited are now added. The pin *m* will then dip into the mercury cup *n*. Contact is made, and the metal will be deposited up to the weight on the pan; as soon as the beam assumes its horizontal position again, contact is broken, and no further separating out of the metal will take place.

Nickel-Plating.—Nickel is frequently used for coating objects. Nickel-plated objects are capable of high polish, and resist oxidation well. An alkaline bath produces dark precipitates, but a slightly acidulated or neutral bath gives white precipitates. According to Roseleur the following mixture is used for the

nickel-plating of iron and steel: Nickelous ammonium sulphate, 1 kilogramme; ammonium sulphate, 150 grammes; water, 24 litres. For copper, zinc, tin, and brass, the following: Nickelous ammonium sulphate, 1 kilogramme; ammonium sulphate, 200 grammes; water, 30 litres. For an anode, a rolled nickel plate suspended from a nickel wire is used. The slightest amount of copper in the bath gives a yellow colouration to the nickel-plated objects. Sodium sulphate, which precipitates all the metals except nickel, is often added to the bath.

Objects are also coated with platinum, lead, zinc, tin, iron, cobalt, and many other metals too numerous to mention. Not only metallic bodies, but objects of glass, porcelain, etc., may receive electro-depositions. To coat the inside of metal tubes, Towle gives the following plan: The tube E F, the inside of which is to be coated, is placed upon a frame A B C D, Fig. 588. The rod *a b*

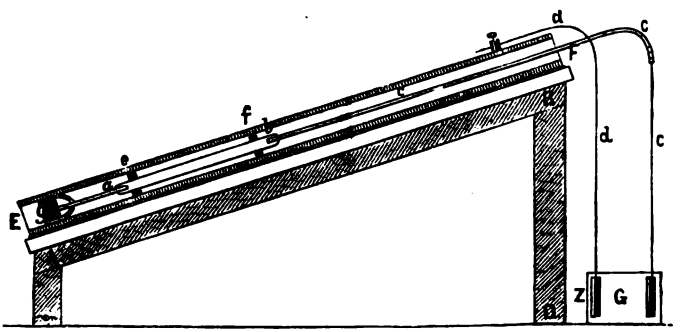


Fig. 588.—The Lining of Tubes.

consists of the same metal as that with which the sides of the tube have to be coated; *c* is a copper wire covered with gutta-percha; *g*, *e*, and *f* are india-rubber corks, to prevent contact of *a b* with the inside of the tube. The metal-salt solution is then introduced so as to entirely cover the rod *a b*, the copper wire *c* is connected with the positive, and the tube with the negative pole of a battery G, by means of the wire *d*. To make the deposit uniform, the metal rod *a b* is moved up and down, and the tube itself turned several times.

The Postal Telegraph Company, New York, uses 200 copper baths, and 25 large dynamo-electric machines, for the coppering of steel telegraph wires. From every ton of copper used for the baths, 15 to 20 ounces of silver are obtained, being separated out by the electric current. According to the *Engineering and Mining Journal*, this covers the direct expenses of the coppering process. In 1883, 100 kilogrammes of wire, having a length of 10 English miles, were coated with 250 kilogrammes of copper per day.

The electric current is also used for *freeing objects from the electro deposit*, by making the object the positive, and the plate the negative electrode. This method, for instance, is used for adjusting the weights of coins. For the adjustment of coins that have very nearly the same overweight, an apparatus

such as is shown in Fig. 589 may be used. The coins that are too light can be similarly adjusted. In the Indian mints both kinds of adjusting are brought about at the same time. Two frames are placed in the potassium cyanide bath; coins which are too heavy are placed in one, those that are too light in the other frame. The coins which are too light are then connected with the negative pole, and those that are too heavy are connected with the positive pole. At the mints of Bombay, 5,000,000 coins are adjusted annually by this method, the weight of the coined silver being 1,320,800 kilogrammes. Compared with the older method, the new plan caused a saving of £1,400 sterling per annum.

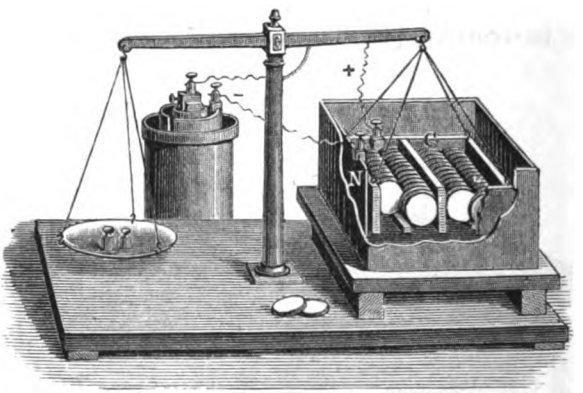


Fig. 589.—Adjusting Coins.

Electrotyping.—By electrotyping proper is meant that process which produces a metal coating sufficiently strong to be removed, and to form an independent object. The metal in solution is separated out at the kathodes; when separated it proves to be a faithful copy; the only difference is that the raised portions are sunk, and the sunk portions are raised in the copy; the copy, therefore, forms a negative of the original. To obtain a positive copy, a cast has to be taken from the negative. The negative is called the mould or matrix. Moulds are very simply prepared; if the object to be copied is a conductor, it is placed in a bath, as a rule, consisting of a slightly acidulated solution of copper sulphate, and connected with the negative pole of the source of electricity. The deposit portion of the object is covered with a non-conducting substance, as, for instance, wax, varnish, etc., so that it may be easily removed. Although moulds prepared in this manner are very strong and exact, they are very expensive and require much labour. The substances usually employed for moulds are: alloys, lead, sealing-wax, wax, gutta-percha, etc. Of the alloys, only those can be employed that melt at a low temperature, as, for instance, Rose's metal, which consists of 2 parts of bismuth, 1 part of tin, 1 part of zinc, and melts at 94° C. Wood's alloy, which melts at 76° C., consists of 2 parts

of cadmium, 8 parts of bismuth, 4 parts of lead, and 2 parts of tin. For objects that can stand a temperature of 108° C., Böttcher recommends an alloy that melts at this temperature, and gives very fine and accurate casts; it consists of 8 parts of bismuth, 8 parts of lead, and 3 parts of tin. Moulds of these or similar alloys are obtained in different ways. As a rule, the alloy is poured upon a horizontal surface, and the coin or object of which a cast is required is pressed upon the mass. When the alloy has hardened it is immersed in the bath as kathode. It is difficult to prevent the formation of oxides on the surfaces of the alloys; hence, where very accurate copies are required, it is better to use gypsum moulds, or moulds of similar substances. Gypsum casts may be taken of objects consisting themselves of gypsum, wood, marble, metal, etc., by using gypsum that is fresh, and of the best quality, and is made into a paste by mixing 2½ parts of water with 1 part of gypsum. In order to enable the mould to be easily separated from the object, if the latter consists of metal, it is well oiled, in other cases the object is coated with graphite or a solution of soap. The cast of a coin is obtained by Brandley in the following manner: Paper is wound round the edges of the coin to be copied, so as to form a flat vessel, the bottom of which is formed by the coin, and the walls by the paper. The coin is then oiled, and the gypsum paste placed upon it; to prevent air bubbles remaining behind in the gypsum, it is advisable first to coat the coin with a thin layer of gypsum by means of a brush, and then add gypsum to the desired thickness. After the gypsum has hardened, the paper is removed from the edges of the coin, and the mould can then be easily separated from the original. The mould, with the impression upwards, is then allowed to dry either in the sun or an oven. Very uniform surfaces are obtained by immersing the mould in molten wax, stearin, and similar substances, for the purpose of filling up the pores of the gypsum mould. When the object to be copied is of such a shape as to make the removal of the mould difficult, it has to be made in sections —but even then it is desirable, of course, to have as few portions as possible. The object, after having been oiled or soaped, has a certain portion coated with gypsum paste. When hardened, the cast is removed and its edges smoothed and soaped. It is then placed in its position again, and a second portion of the object treated similarly, until the whole is copied. The different portions are held together by a layer of gypsum, which covers the whole of the outside portions. In some cases the deposits are made from the several portions, and then soldered together.

The mixture given by Riess for taking casts will be found of use: it consists of 4 parts of molten asphalte, 12 parts of white wax, 4 parts of stearin, 2 parts of tallow; soot is added to the paste until it is of a deep black colour. The sticking of this material to the original is prevented by mixing with it finely-powdered gypsum. If the object to be copied consists of gypsum, it is placed in lukewarm water, is taken out when the water has well entered its pores, and the paste is then applied to it.

Gutta-percha is of very great service for the making of moulds. This is

obtained from the pine of the *Isonandra gutta*, which belongs to the family Sapotaceæ, and is found in the neighbourhood of Malacca, and Borneo. For copies from small objects the mass is simply softened by the heat of the hand, and pressed upon the original; when the gutta-percha hardens, it is easily removed from the object, provided it was well coated with graphite before it was used. To copy larger objects, some kind of press has to be used. For very delicate objects, a mixture of 10 parts of glue and 1 part of brown sugar forms a suitable paste.

After the moulds have been made they are *prepared for the bath.* This preparation is very simple. When the mould consists of metal, all that is required is either to give it a very thin coating of oil, or to coat it with a layer of graphite, or with a metal film. Such films, for instance, are easily produced upon copper plates by exposing them to iodine vapours, which converts the copper into copper iodide. When exposed to sun-light, the latter is again decomposed, the iodine escapes, and a thin film of powdered copper remains upon the plate. If the mould consists of a material that is not a good conductor of electricity, we have first to ascertain whether it has a smooth or porous service. Porous moulds of wood or gypsum, for instance, must have smooth surfaces before they are made to conduct electricity. This is usually obtained by dipping them into molten wax or stearin. Graphite is mostly used for the purpose of making the mould conduct electricity. The best quality is used in the form of a fine powder, and is applied to the mould by means of a brush. The success of the electro-deposition depends upon the uniformity of the graphite coating. Graphite, in comparison with the metals, is a bad conductor of electricity; hence attempts have been made to substitute metals for making conducting surfaces for the moulds; for this purpose silver compounds are mostly used. In order to coat the object with sulphuret of silver, it is usually placed in an alcoholic solution of silver nitrate; care is taken that the fluid is uniformly applied, and that no fluid is allowed to remain behind in the crevices where it might crystallise, and thus interfere with the electro-deposition. The mould while wet is exposed to a stream of sulphuretted hydrogen.

After the surface of the mould has been made a conductor of electricity, it has to be connected with the wire from the source of electricity. Metallic moulds have the wire soldered; moulds of gutta-percha, wax, etc., have the hot wire simply stuck in. For round objects, such as medals or coins, it is well to allow the wire to surround the mould. Connection is made by allowing the graphite or metal layer to extend to the wire. All the metallic portions that are to have no deposition must be covered with substances such as gutta-percha, wax, etc.

The simplest form of this kind of electro-deposition is the *reproduction of coins* and *medals.* The apparatus generally used is shown in Fig. 590. To the copper bar *a b* the copper plates K K are fastened, and arranged in the trough A, as shown; wires *m m*, from which the coins and medals are hung, are connected with the zinc rod *c d*, the portions of *m m* which rest upon

the copper rod *a b* being insulated. The battery D D has its negative pole (zinc pole) connected with the zinc pole of the bath, and therefore with the coins and medals, and the positive pole is connected with the copper rod and copper plates. Air-bubbles, which would interfere with the uniform deposition of the copper, may be prevented by either immersing the moulds in alcohol before bringing them to the bath, or by gently heating the bath, or by removing them with a hair brush. The bath is made of pure copper sulphate and distilled water slightly acidulated with sulphuric acid. To maintain it in a concentrated condition, a little sack containing crystals of copper sulphate is placed in it. The copper deposits may then be coated with silver or gold as described already.

The reproduction of *busts*, *statues*, etc., is the most difficult branch of the business of electro-deposition. Lenoir thus describes the process: One half of the

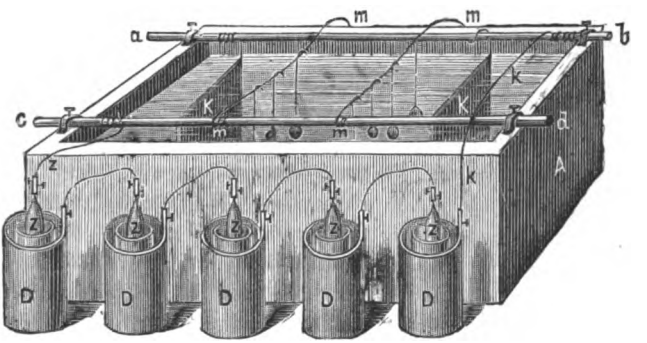


Fig. 590.—Electrotype Apparatus.

statue is covered with gypsum, and at the edges of this gypsum holes are made; the remaining portion of the statue is then covered with a mixture of gutta-percha, resin, and fat, having projections to meet the apertures made in the first half. When this substance has become hardened, the gypsum cover is removed from the statue, leaving the mixture with its projections on the statue. The second half of the statue is then covered with the mixture, and after the substance has hardened, the inside of this mould, consisting of two halves, is coated with graphite. The two portions of the mould, which hold together by the pegs and holes, are then ready to be placed in the bath.

In order that the copper may be uniformly deposited, an anode that has something the same shape as the mould is placed inside it, so as to be at fairly equal distances from each side of it. It is not advisable to have the anode of the same metal as that separated out by the electrolysis. Lenoir uses a frame-work of platinum wire, which is so placed inside the mould as not to touch it at any point. In Fig. 591, A represents the vessel; it is a wooden trough, well varnished, containing the copper sulphate solution; B is the mould, with its platinum anode; the several platinum wires are united at *a*, and fastened to one of the

metal pins *s* on the bar T T, which is connected by means of the wire K, to the positive pole of the source of electricity Z; the wire coming from the negative pole of it is connected with the graphite layer by means of the screw C and copper strip *k*. To maintain the solution concentrated, little sacks, containing crystals of copper sulphate, are placed in the bath. When the copper begins to separate out, the solution inside the mould contains an increasing proportion of sulphuric acid. As copper sulphate has a greater specific gravity than sulphuric acid, the former will enter the mould from below, and push the latter upwards until it comes in contact with the crystals of copper sulphate, when it will dissolve them. As platinum frames are expensive, Sonolet substitutes lead. Lead, when used as the anode, becomes coated with a brown layer of oxide, which protects it from further reactions, and also favours the generation of oxygen. The lead core, which is to serve as anode, is shaped roughly like the body, and is then perforated so as to allow the fluid to circulate freely.

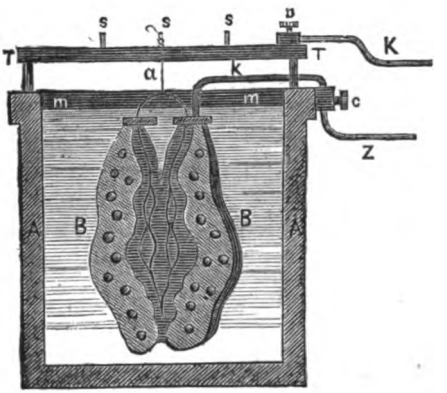


Fig. 591.—Arrangements for a Statuette.

When one copy only is required, moulds of stearin or wax are generally used, the mould being made to conduct electricity, and care being then taken that the copper is uniformly deposited to about the thickness of a sheet of paper. The mould is then placed in hot water. The wax melts and flows out of the thin copper case, which is carefully cleaned inside by means of potash and alcohol, and then coated outside with wax. When now brought into the bath, copper will be deposited inside to the desired strength.

Fac-similes of Very Large Objects.—There are two ways of obtaining very large objects: either the deposits are produced separately and soldered together, or the whole deposit is made at once. For the first method a cast of the object is first obtained, and then divided into as many portions as desired. These portions are brought separately into the bath. The edges of the deposits are smoothed, fitted well together, and covered by a wire frame for keeping the several portions together, the junctions are then soldered. Christophle, of Paris, prefers to obtain the copper deposit in one piece, and uses for this purpose a lead core for anode.

Objects obtained by electro-deposition are preferable to those obtained by casting; and the former method is both simpler and cheaper. Electro deposits are also homogeneous, tenacious, and malleable, and, as experiments have clearly proved, are not so porous as casts. Bouilhet exposed two similarly-shaped plates (the one cast, the other obtained by electro-deposition) to a

hydraulic pressure. Water passed through the cast plate after a pressure of twelve atmospheres, whilst the plate obtained by electro-deposition sustained a pressure of twenty atmospheres before water was observed to pass through it. To produce a simple plate by the method of electro-deposition is about twice as expensive as to produce the same plate by casting; but when a copy of a statue has to be produced in metal, it would be far more expensive to have it cast than to reproduce it by means of electro-deposition. In the production of objects of art by casting, the metal is not allowed to have a thickness of less than 8 to 15 millimetres; not that this thickness is required for the sake of durability, but simply because it cannot be produced thinner. Even for the largest objects that have to resist the influence of temperature for any length of time, the metal need not be thicker than 1·5 millimetres, for the inside of the figure can be supplied with a frame-work, etc., which will insure durability. Statues produced by the method of deposition, as a rule, have a thickness of from 3 to 5 millimetres of pure copper, which might be increased at pleasure by a mixture of lead and tin, or copper and zinc. In many cases the metal need only be very thin, so that it would be a great waste of metal to have the object cast.

Maps.—Electro-deposition is greatly used in the geographical arts. O. Volkmer, Secretary of the Technical Department in the Geographical Institute, Vienna, has given the following details in his report respecting methods of producing printing-plates for maps, etc., by electro-deposition instead of having them engraved. The process is as follows: From the original drawing, which has to be very distinctly and finely drawn in Indian ink, a reversed and reduced photographic negative is taken. The reduction of four-fifths or three-fourths of the original size insures a clearer copy of the original. From this negative a gelatine relief is taken; for this purpose paper is covered with a coloured gelatine solution, and then treated with a solution of potassium bichromate. The paper being thus prepared, when wet and exposed to light, the gelatine will not dissolve at the uncovered portions, but will do so at the covered portions. To obtain the gelatine relief, the paper is put into a frame and exposed to sun or electric light. The pigment paper is then placed with its front side upon a silver-plated copper plate under water. The plate is afterwards placed in cold water to remove the potassium bichromate, and again in warm water, having a temperature of 30° to 35° Réaumur (100° to 110° F.), to develop the gelatine relief upon the silver-plated copper plate. The relievo is then again treated with distilled warm water, until the lines are well defined upon the bright silver surface. After the plate has been allowed to dry for about ten to twelve hours it possesses a steel-hard relief.

The gelatine relief is made to conduct electricity by coating it with graphite, and it is then placed in a bath; care is taken that deposition takes place pretty rapidly; after about an hour the plate is taken out and well cleaned, and it is then placed again in the copper bath, and left in it for about three to four weeks. The cast is now removed, and irregularities corrected. Perfectly

well defined pictures are only obtained by this method after some copies have been taken.

Reproduction of Copper Plates.—The copper plate is first silver-plated, then passed through a solution of iodine in alcohol (1 part of iodine in 20,000 parts of alcohol), and is then exposed to the light. A very fine layer of silver iodine is produced, which facilitates the removing of the copper deposit. If the original is a steel plate the copper bath must not consist of copper sulphate, because copper would be deposited without the current, and, at the same time, steel would dissolve.

Electrotype Art Processes.—To replace expensive wood engravings, a copper plate is blackened with sulphuret of potassium, and then coated with a thin layer of wax. The drawing is then made with a needle. An electrotype copy is made of this drawing and fastened to a wood block; very good copies have been obtained by this method. This process has been known for many years under the name of glyphography. More recently, paraffin has been substituted for the wax, and gives much better results, not being so apt to clog the lines. It is also whiter, which is better for the eye of the artist. The black ground is now usually produced by a thin coat of oxide of silver.

Fac-simile copies of whole pages of type are now largely prepared by electro-deposition, taking the place on the printing machine of both the original type, and the stereotyped plates of type-metal formerly used. These copper plates are both far more durable, and in colour-printing give more brilliant colours, which were apt to be dulled by contact with the lead of the type-metal. Indeed for some delicate colours it is even found advisable to deposit on the face of the copper a further thin film of silver. The moulds from the type are usually taken in a plate of *cold* wax by the pressure of a hydraulic press, and this is blackleaded with unusual care, and with the finest black lead, else the very small countless depressions formed by the type would escape. To avoid small air-bubbles in these depressions was for many years a great difficulty, but it is now easily surmounted by the simplest means: the mould is held under a high-pressure stream of water till all the air is driven out, and the mould is thoroughly wetted to the bottom of the smallest crevice. Copper is deposited as usual, either by battery, or more usually of late by dynamo-machines. The copper "shell," or fac-simile, when removed and washed, is filled to the depth of a quarter of an inch with melted type or softer metal. The heat of this process more or less warps the fac-simile face of the shell, which should be a true plane; and this is now remedied by punching up the metal from behind upon a true iron surface. Finally the plate is fixed in a lathe or planing machine, and the back made smooth and parallel to the face, after which the plate is mounted to the same height as movable types on blocks of metal or wood. Some large printing offices occupy two or more machines more or less constantly at this kind of work.

Wood engravings are also copied in the same way, and the fine illustrated works now published monthly or weekly in nearly every large city in Europe are almost exclusively printed from electrotype duplicates of the original wood

engravings. Indeed they could be printed in no other way; because a large engraving is composed of many pieces of box-wood screwed together, and in printing from the wood it would be almost impossible to prevent some of the "joins" in the wood from appearing. In the solid copper duplicate all such blemishes are carefully dressed down and repaired before printing.

Copying from Nature.—Plants, insects, etc., are copied in the following manner by Auer in the Government office at Vienna: The plant is placed between sheets of blotting-paper, pressed, and allowed to dry; it is then placed in water, and again left to dry. The plant is then laid upon a smooth lead plate, covered with a steel plate, and exposed to pressure, and a mould is obtained from the impression left on the lead; the copper plate prepared from this mould is used in the press.

For etching plates Smee gives the following directions:

The copper plate is covered with a substance such as wax, pitch, resin, etc. The drawing is then made with a needle so that the bright copper is visible. The plate is then placed in a copper bath, forming the positive electrode. The oxygen given off at the positive electrode oxidises the copper at the bright portions, and this oxide dissolves in the sulphuric acid. At the negative electrode, which is also a copper plate, copper which is separated out is deposited. When etchings are required which are not uniform, the copper plate must be taken out of the bath, and the portions that are not to be etched further must be covered with wax.

ELECTRICITY AS A MOTIVE-POWER.

Definitions.—By electric transmission of power is meant the utilisation of electrical energy for mechanical work. Mechanical work is converted into electricity, which is conveyed to some distance, and then again, by means of a machine, re-converted into mechanical work. The great object of all inventors and mechanicians in this department is to cause as much as possible of the energy produced to be utilised for work. The electric transmission of power differs from telegraphy; here the electric current is conveyed considerable distances, and when it has arrived at its destination the current does mechanical work, but the quantity of work transmitted does not come into account.

The theory of electric transmission of power is at present far from being established; and for large distances and great power no experiments have as yet been made that are practically of use. The careful experiments made by Marcel Deprez gave very interesting results from a theoretical point of view; but these would require to be practically tested before they could be made use of commercially. The solution of the problem has, however, been partially accomplished when the distances are not too great and the power required is not very large. The machines, by means of which electricity does mechanical work, are called electro-motors.

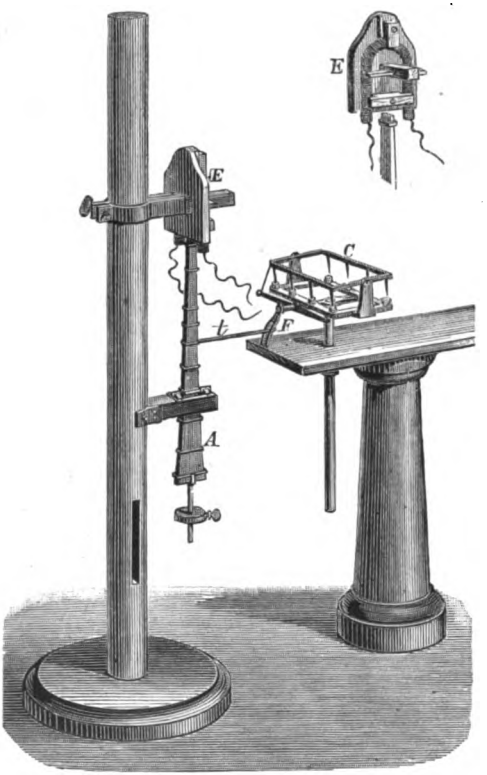


Fig. 592.—Negro's First Electro-Motor.

HISTORY OF ELECTRO-MOTION.

Older Electro-Motors.—It would seem that the first motor (shown in Figs. 592 and 593) was constructed by Salvatore da Negro, Professor at the University of Padua, in 1830. The steel magnet A is allowed to oscillate about an axis, so that its upper end moves between the poles of the electro-magnet E (drawn separately). When a current flows

through the coils of the electro-magnet, the upper end of the permanent magnet A will move so that it approaches the dissimilar, and moves away from the similar poles of the electro-magnet. If the poles of the electro-magnet are made to change constantly, the magnet A will be made to oscillate. The change of direction of the current is brought about by the commutator C, which is set in motion by the magnet A, by means of the rod *t* and forked piece F. The commutator is inserted in the same circuit as the electro-magnet, and reverses

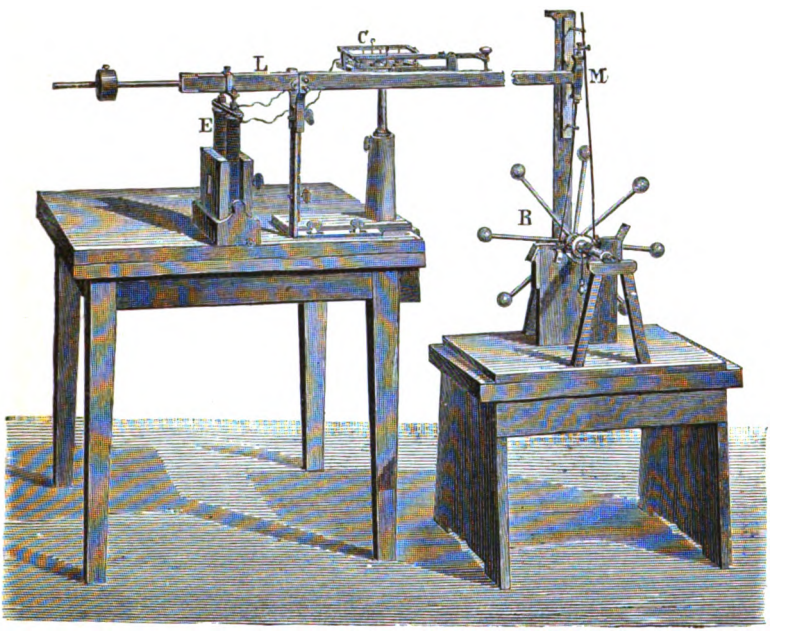


Fig. 593.—Negro's Second Electro-Motor.

the direction of current exactly at the moment when the permanent magnet has approached the one or the other pole of the electro-magnet.

By means of the second apparatus (shown in Fig. 593) a continued rotation is produced. Here the electro-magnet E influences an armature fastened to the horizontal lever L, by means of which the motion of a commutator C is also brought about. From the projection M of the lever a rod catches in the teeth of a wheel, keeping it in motion. To make this motion more uniform, pieces of wood or spokes which have balls at their ends are fastened radially upon the axis of the toothed wheel. Jacobi, the inventor of electro-deposition, published in 1834 the construction of an electro-motor (Fig. 594), which, after undergoing several alterations, was employed for propelling a vessel on the Neva. The apparatus consists of two series of horse-shoe electro-magnets fastened upon two supports; between these supports, upon a

horizontal axis, is a six-armed wheel, each of whose arms carries a couple of magnets parallel to the axis. Upon the same axis is fastened a commutator of four discs, which changes the direction of the current in the coils of the electro-magnets at that moment when the straight electro-magnets are opposite the poles of the horse-shoe magnets. If the straight magnets are between two succeeding horse-shoe magnets, one of the latter influences the straight magnet with a repelling force, the other with an attracting force. When, therefore, the pole-screws of the motor are connected with a battery by means of the straight magnets and spur wheel, continued rotation is obtained. Th. du Moncel and Geraldy (in *L'Électricité comme Force Motrice*) give the following details of

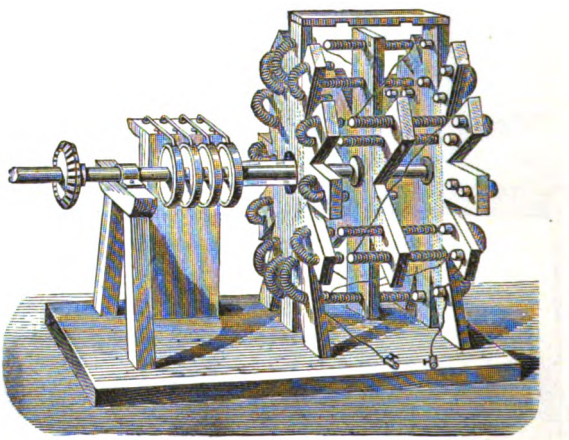


Fig. 594.—Jacobi's Electro-Motor.

experiments made with this motor for propelling a vessel on the Neva. For the first experiment was used a battery of 320 Daniell elements, in which each of the copper and zinc plates possessed a surface of 225 square centimetres. With this force the vessel moved with a velocity of 2,300 metres per hour. For the experiments in 1839, Jacobi used a battery consisting of 128 Grove elements of the same surface area of plates. With this he obtained a velocity of 4,170 metres per hour. The vessel itself measured 8·4 metres by 2·25 metres, and carried twelve persons. These experiments are said to have cost about 60,000 francs, and were paid for by the Emperor Nicholas.

The motor constructed by Elias in 1842 resembles Pacinotti's ring in appearance, and consists of two concentrically arranged iron rings F and T in Fig. 595, each having six groups of coils. The outer ring is fixed, and is carried by the supports C C'. By means of the six layers of wire, which are wound alternately in opposite directions, the whole ring is divided into six electro-magnets, the poles of which A A' acquire alternately north and south magnetism when a current passes through the coils. The inner ring T is constructed in a similar manner,

and has also six poles *a a'*. The inner ring, however, can rotate round a horizontal axis supported by *p p'*. The commutator *c* is fastened upon the same axis, and consists of six metal strips at equal distances from each other. Strips 1, 3, and 5 are connected with the wire *f*; strips 2, 4, and 6 are connected with the wire *f'*. Over this commutator slide the springs R R', which are connected with the clamps B B'. The current for the outer ring is conveyed by means of the wires *g g'*. The motor can be used with one battery for each, or the same battery for both rings. In the first case the pole-wires of the one battery are connected

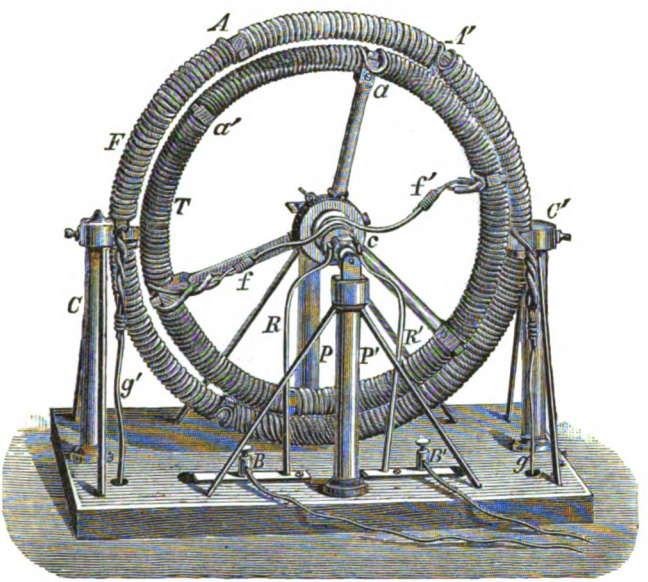


Fig. 595.—Elias's Electro-Motor.

with *g g'*, the pole-wires of the second with the screws B B'. The current of the first battery enters at *g*, and divides at C' into two branches, one of which flows through the coils of the upper half of the ring, and the other through the lower half; both branches unite and flow through *g'* back to the battery. The current of the second battery passes through the screw P, spring R, and the commutator, and turns off to either group 1, 3, 5; or 2, 4, 6, according as a metal strip with an even or uneven number comes under the spring R. As each of the springs slides alternately over the metal strips of the one or the other group, the direction of the current in the spirals of the inner ring has constantly to change, and this causes a continued change of the poles *a a'*, and rotation of the ring T. If, for instance, A' is a north pole, *a* has to be a south pole; *a* is therefore attracted by A', and repelled by A. If the south pole *a* has now arrived at north pole A', the south pole *a* is immediately converted into a north pole because the springs R R'

have also arrived at the next metal strip, causing a reversion of the current in the coil of the movable ring. The north pole *a* is now repelled by the unchanged north pole A′, and attracted by the south pole c′, hence the inner ring continues its rotation in the same direction. When used with one battery the current separates into two branches, one branch flowing through the coils of the inner, the other branch through the coils of the outer ring.

Froment constructed several motors during the years 1844 to 1862, to which he gave different shapes. We shall describe only two of these; and for further information refer to Th. du Moncel and Geraldy's work, *L'Électricité comme*

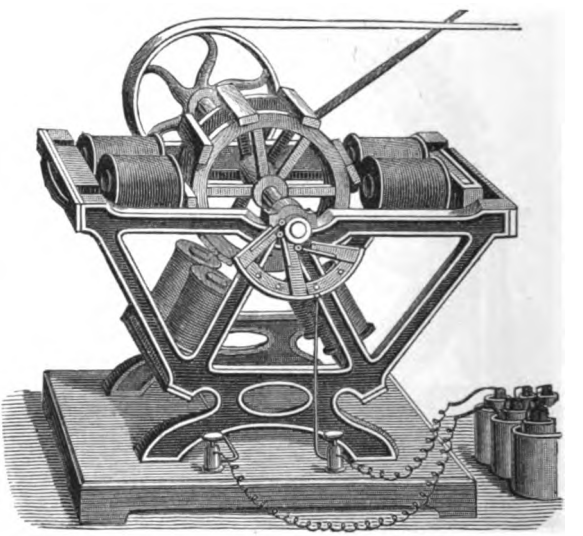


Fig. 596.—Froment's Electro-Motor.

Force Motrice. The motor constructed in 1845 is shown in Fig. 596. Four electro-magnet couples are fastened upon a frame, as shown. A wheel rotates between the poles of these electro-magnets, and carries soft iron bars fastened upon its circumference, which serve as armatures for the electros. The attraction which these electros exert upon the armatures brings about a continued rotation. The current from a battery is first conveyed to a commutator, which supplies the several magnet couples with continuous and alternating currents. The commutator consists of a series of contacts fastened to the shaft of the wheel, over which slide contact wheels or buttons pressed by springs. Thus it happens that those two electro-magnet couples are supplied with currents which are being approached by the iron armatures of the wheel. This motor is still used for toys or demonstrations in physical laboratories.

The largest electro-motor which Froment constructed is shown in Fig. 597. The electro-magnets are fastened to six cast-iron supports, as shown in the figure.

The axis of this prism forms a vertical shaft carrying rotating soft iron armatures. To the top of the shaft is fastened a horizontal wheel, the teeth of which catch

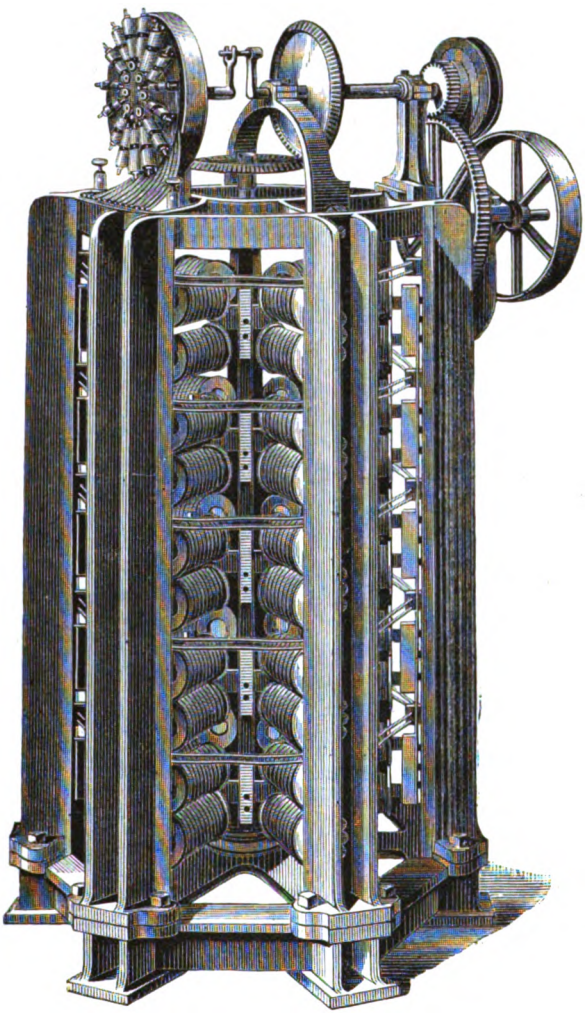


Fig. 597.—Froment's Second Electro-Motor.

into a vertical wheel, which causes the rotation of the commutator (to the left of the figure). This consists of a series of contact rollers, which come alternately upon insulated and non-insulated portions of the disc below, when the shaft rotates. In spite of the size and solid construction of this motor, only very moderate results were obtained by means of it.

Hjorth took out a patent for a motor which obtained the large medal at the London Exhibition, 1851. A representation of this motor is shown in Figs. 598 and 599. The electro-magnets A A are conically hollowed inside, and fastened to the axis B, about which they rotate. The electro-magnets C C are conically shaped outside, and can slide along the guide-bars D D; their motion being transmitted by a crank to the shaft carrying the fly-wheel. The machine has a commutator which is similar in construction to the slide-valve of a steam-engine,

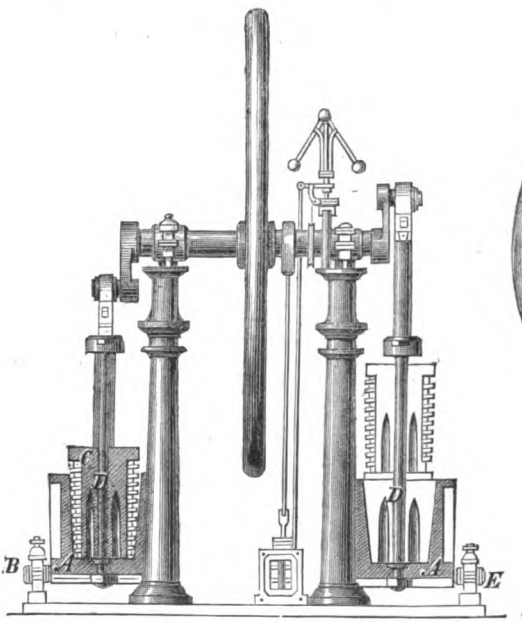


Fig. 598.—Hjorth's Electro-Motor.

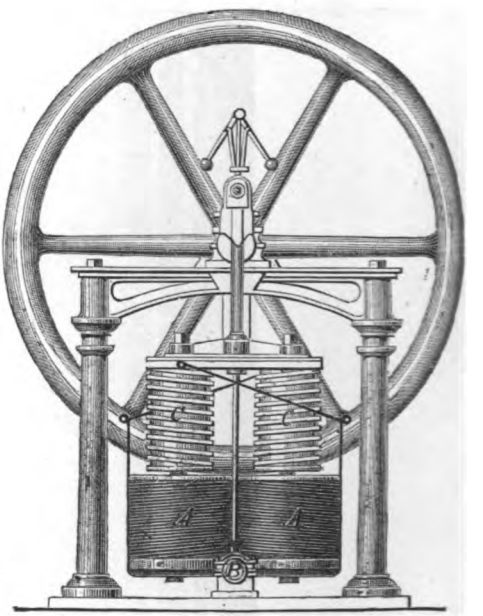


Fig. 599.—Hjorth's Electro-Motor.

and like it receives motion from an excentric on the shaft. This slide allows the electric current to pass alternately into the one or other of the two electro-magnets. Owing to the construction of the magnets, the force of attraction of the horse-shoe magnets A upon C on one side is stronger than that on the other side. If in one group of magnets the movable one has finished its motion, the current in this group is reversed by means of the commutator, and produced in the other group. This causes an upward motion of magnet C in the first, and a downward motion of magnet C in the second group, so that a motion similar to that in a steam-engine is produced.

Of the older motors based on the attraction and repulsion of magnets, the ring devised by Pacinotti, a description of which has been given already, is a typical example. Of the motors for which solenoids have been used, the

one constructed by Page, and shown in Fig. 600, was one of the earliest. The two iron cores C and D are placed centrally over the solenoids A and B, and fastened to the connecting rods of the beam E G, which is movable about F. The continuation of the beam has at H a third connecting rod, which sets the fly-wheel in motion by means of the crank K. Upon the horizontal axis of the latter is fastened the excentric L, which causes the coils of the solenoids A and B to be alternately inserted in the circuit of the battery. If the current

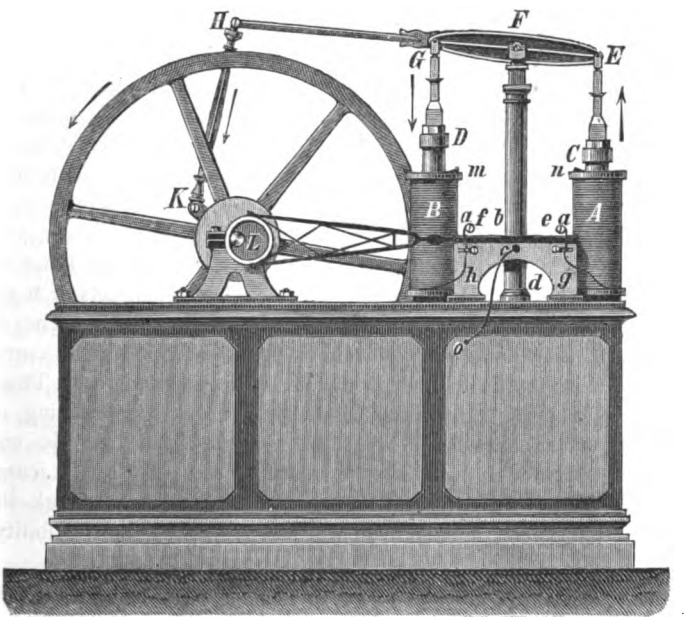


Fig. 600.—Page's Electro-Motor.

flows through B, the iron core D will be drawn into the solenoid, and the left side of the beam will descend. When D has arrived at its lowest position, the current through B will be interrupted by the motion of the excentric, and will flow through A. C is therefore drawn into A, and D rises again. Although much was expected from this motor, its efficiency is not such as to recommend it for practical purposes.

In the older electro-motors, as a rule, more or less iron matter is alternately magnetised and demagnetised, so as to attract a corresponding number of armatures or iron cores, and to cause motion. This motion, however, is not uniform, and consists of a series of impulses, which is objectionable. The defects of the older apparatus may be summed up in the following three points: 1. Impracticability of continued motion due to disconnected impulses. 2. Generation of considerable quantities of heat due to the continued change of

the magnetic condition. 3. Incomplete utilisation of the magnetic forces, in consequence of the arrangement of the affected parts.

The first drawback is not entirely overcome in modern machines. Even, for instance, in the Gramme ring, the motion is due to impulses, although they follow each other so rapidly, that for practical purposes they might be considered continuous. The generation of heat is considerably diminished by having fixed magnets, which retain the same kind of magnetisation. The armature is not now magnetised and demagnetised, but a shifting of the magnetic poles takes place. Modern machines have the parts that are to influence each other better arranged, and their armatures rotate close to the poles.

Convertibility of Electric Machines.—If the armature of a dynamo-electric machine is made to rotate, as does the ring of a Gramme machine, currents are produced in the coils of the ring which may be utilised for the induction of the electro-magnets, and for other purposes in the external circuit. The machine, therefore, converts mechanical work into electricity. If the reverse be now adopted, *i.e.* if the poles of such a machine are connected with the pole-wires of a source of electricity, the current of the latter will have to pass through the coils of the machine, the electro-magnets of it will come under induction, and will influence the spirals of the armature. The armature will then begin to rotate, and will continue to do so as long as the current from the source of electricity flows through the coils of the machine. This motion of the armature can be transmitted by belting, etc., to a working machine, *i.e.* a machine for mechanical work. In this case the electric current is converted into mechanical work, or the exact reverse of the first case. This property of dynamo-electric machines to convert mechanical work into electricity, and electricity into mechanical work, is called the convertibility of the machine.

It is the principle of convertibility which makes the electric transmission of power possible. It is one of the earliest known of scientific principles that if we apply heat we obtain motion (as in the steam-engine), and that, inversely, motion produces heat (as by friction). Chemical compounds are decomposed by heat; and inversely, chemical combination is accompanied by a rise of temperature. Each effect has a counter-effect. The application of this law to magneto-electric machines also was first recognised by Pacinotti (*see* p. 239), and was considered by the late James Clerk-Maxwell the most important discovery of the age. Siemens observed the convertibility in 1867. The first public experiment showing the electric transmission of force was made during the Exhibition at Vienna (1873). A Gramme machine, with permanent horse-shoe magnets, driven by a steam-engine, was used for the purpose, and the current obtained was conveyed to a second similar machine about 500 metres distance from the first. The second machine began to rotate, and was made to work a pump. The electric transmission of power for practical purposes was made use of for the first time in the laboratory of St. Thomas d'Aquin, in 1876. Cadiat, engineer of the Société du Val d'Osne, made use of it in 1878.

ELECTRIC TRANSMISSION OF POWER.

We shall now consider the electric transmission of mechanical power more closely. When a dynamo-electric machine is set in motion by a motor, and the currents produced are conveyed to a second machine, the latter may be used for doing mechanical work. The first machine, *i.e.* the one that furnishes the current, is called the primary (French *génératrice*); the second machine, *i.e.* the one that actually does the work, the secondary (*motrice* or *réceptrice*). When the primary machine I, Fig. 601, rotates in the direction of the arrow, currents will be generated in the ring, the direction of which will be such that positive electricity will leave at a_1, and flow into the coils of the electro-magnets, and then to the secondary machine II, returning to machine I at b_1, which represents the negative pole. The current entering the secondary machine at A, flows through the first magnet-arm in the same direction as the hands of a watch move, causing south magnetism in that portion of the arm nearest A. The upper shoe will, therefore, receive north, the lower shoe south magnetism. At a_2 the current divides—one portion flows into the upper, the other portion into the lower half of the armature coils. The two branches again unite and leave the machine at b_2. We have now in the ring armature a spiral through which a current flows, that is to say, a ring-shaped electro-magnet, which is in the immediate neighbourhood of the powerful magnetic poles N_2 and S_2. Let us consider in what manner the ring is magnetised by the currents that flow round it. If we go back again to a_2, where the current enters the ring, we find that the current flows clockwise in the upper half, and counter-clockwise in the lower half of the ring. We shall, therefore, have south magnetism at a_2, and

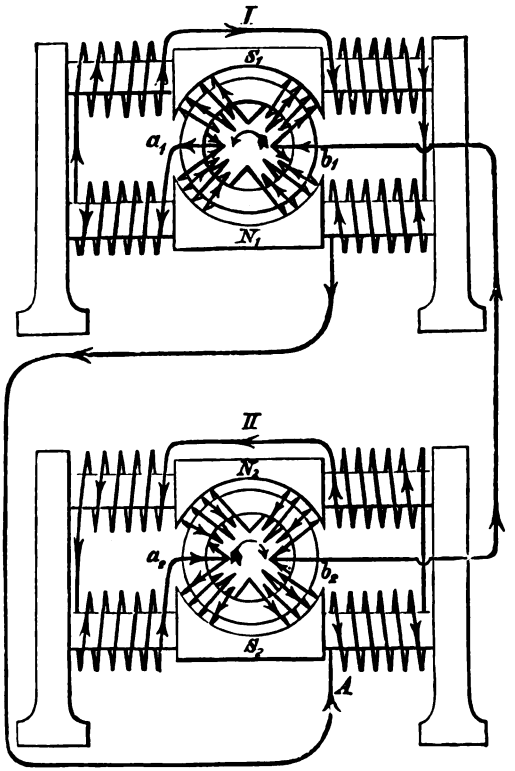


Fig. 601.—The Connection of a Dynamo and Motor.

north magnetism at b_2, and it follows that according to this magnetic distribution the armature will have to rotate in the direction indicated by the arrow. The north pole N_2 attracts the south pole at a_2, and repels the north pole at b_2. The south pole s_2 repels the south pole at a_2, and attracts the north pole at b_2. The resultant of these forces is a couple producing a revolution of the armature. The rotation of the ring will continue as long as machine II is supplied with current.

From Fig. 601 we also see that when the primary machine rotates in one direction, the secondary machine rotates in the other; and further currents are induced in the armature of the secondary machine. What will be the direction of these currents produced by the motion of the secondary machine? The answer may be obtained by reasoning as follows (*see* p. 344): The electromagnets of the primary machine possess a south pole at S, and a north pole at N. As the armature rotates from right to left, it follows therefore that the positive current will leave at a_1. If now the poles of the secondary machine had the same position, that is, if the south were above, and north below, the rotation being from left to right, the positive current would leave the machine at b_2. The position of the poles being reversed, it follows that the current induced in the armature will leave the secondary machine also at a_2, hence the primary current entering at a_2 is met by an induced current which has the opposite direction. We see then that an opposition current is generated in the secondary machine. We know that if two equally strong currents are sent through a conductor, their total effect is equal to 0. With currents of unequal strength, the difference of the two gives the final result. The strength of a current is obtained from the E. M. F., and resistance in the circuit. The E. M. F. of a dynamo-electric machine depends upon the resistance of the circuit and number of rotations of the armature. Let us suppose that two dynamo-electric machines are connected with each other, as shown in Fig. 601. Let us assume that the primary machine makes 1,000 revolutions per minute, and that the speed of the secondary machine is allowed to increase gradually. If a galvanometer be included in the circuit of the two machines, the needle will show the rapid decrease of current in the machine as soon as the secondary machine begins to rotate. The counter-currents produced will increase with the speed of the secondary machine. The needle of the galvanometer will indicate a steady diminution of current, as long as the speed of the secondary machine, which we suppose has no work to do except to overcome friction, etc., continues to increase. The speed of the latter will only increase as long as the primary current is stronger than the opposition current of the secondary machine. The machines being similar in construction and equal in size, it follows that when the speed of the secondary machine has increased until it is the same as that of the primary machine the currents must be also equal, and the needle will point to zero. Let us now consider the case in which the secondary machine has to do work. The extreme case is that in which the ring of the secondary machine is held fast, *i.e.* forcibly prevented from rotating. In this case the secondary machine cannot produce an

opposition current, but acts as a simple circuit of small resistance for the primary machine, the current of which will increase rapidly to its maximum value. What then becomes of the expended energy? It is converted into heat, and the experiment can only last for a very short time without damaging the machines. Suppose now the secondary machine is allowed to do work, say to lift a load: The primary machine receives work from the steam-engine, and furnishes electric currents; the secondary machine receives electric currents, and does work. If the work the secondary machine has to do is only very slight, its speed will not be very much less than that of the primary machine, and the total current in the total circuit will be but small. If the work to be done by the machine is considerable, it will slacken its speed, and also diminish its opposition or counter-current, causing increase of current in the total circuit. If the work to be done is greater than the efficiency of the secondary machine will allow it to do, the rotation will cease altogether, and we have a repetition of the case considered above.

The behaviour of the steam-engine which drives the primary machine is analogous to that of the secondary machine. If, for instance, the work of the secondary machine is only slight, the steam-engine need do but little work: the steam-engine will have to do most work when the secondary machine ceases rotating because of over-work. In each case the secondary machine returns the work transmitted by the steam-engine to the primary machine; a portion of the energy being of course lost in heat and in overcoming friction, etc. A portion of the transmitted work will be converted into heat as long as the secondary machine rotates; if the latter ceases to rotate because of the over-strain, the whole of the energy will be converted into heat. By expressing the relations here indicated between the current, counter-current, and work done in the form of equations, their consequences will probably become more clearly apparent, and therefore we will proceed to put the theory in the equational form.

THEORY OF THE ELECTRIC MOTOR.

Upon the existence and magnitude of this counter-electromotive force depends the degree to which any given motor enables us to utilise electric energy that is supplied to it in the form of an electric current. In discussing the dynamo as a generator, we have pointed out many considerations, the observance of which would tend to improve the efficiency of such generators. It is needless to say that many of these considerations, such as the avoidance of useless resistances, unnecessary iron masses in cores, and the like, will also apply to motors. The efficiency of a motor in utilising the energy of a current depends not only on its efficiency in itself, but on another factor, namely, the relation between the electromotive force which it generates when rotating, and the electromotive force at which the current is supplied to it. A motor which itself in running generates only a *low* electromotive force cannot, however well designed, be an *efficient* or economical motor when supplied with

currents at a *high* electromotive force. A good *low-pressure* steam-engine does not become more "efficient" by being supplied with *high-pressure* steam. Nor can a high-pressure steam-engine, however well constructed, attain a high efficiency when worked with steam at low pressure. Analogous considerations apply to dynamos used as motors. They must be supplied with currents of electromotive forces adapted to them. Even a perfect motor, one without friction or resistance of any kind, cannot give an efficient or economical result if the law of efficiency is not observed in the conditions under which the electric current is supplied to it.

Now we have shown, on page 345, that the efficiency with which a perfect motor utilises the electric energy of the current depends upon the ratio between this counter-electromotive force and the electromotive force of the current that is supplied by the battery. No motor ever succeeds in turning into useful work the whole of the currents that feed it, for it is impossible to construct machines without resistance, and whenever resistance is offered to a current, part of the energy of the current is wasted in heating the resisting wire. Let the symbol W stand for the whole of the electric energy of a current, and let w stand for that part of the energy which the motor takes up as useful work from the circuit. All the rest of the energy of the current, or $W - w$, will be wasted in useless heating of the conductors that offer resistances.

But if we want to work our motor under the conditions of greatest economy, it is clear that we must have as little heat wasted as possible; or in symbols, w must be as nearly as possible equal to W. We have shown, mathematically, that the ratio between the useful energy thus appropriated, and the total energy spent, is equal to the ratio between the counter-electromotive force of the motor, and the whole electromotive force of the battery that feeds the motor. Let us call this whole electromotive force with which the battery feeds the motor E, and let us call the counter-electromotive force e. Then the rule is:

$$w : W = e : E.$$

Or if we express the efficiency as a fraction:

$$\frac{w}{W} = \frac{e}{E}.$$

But we may go one stage further. If the resistances of the circuit are constant, the current c observed when the motor is running will be less than C, the current while the motor was standing still. But from Ohm's law we know that:

$$c = \frac{E - e}{R}.$$

$$\text{Hence } \frac{C - c}{C} = \frac{e}{E} = \frac{w}{W}.$$

From which it appears that we can calculate the efficiency at which the motor is working by observing the ratio between the fall in the strength of the current and the original strength, a law of efficiency which has been known for twenty years, but has, until very lately, been strangely misapprehended.

We have dwelt, in page 346, on the difference between efficiency as regards speed of working and efficiency as regards economy. Jacobi's law concerning the maximum work of an electric motor, supplied with currents from a source of given electromotive force, refers to the former. The mechanical work given out by a motor is a maximum when the motor is geared to run at such a speed that the current is reduced to half the strength that it would have if the motor were stopped. This, of course, implies that the counter-electromotive force of the motor is equal to half the electromotive force given out by the battery or generator. Under these circumstances only half the energy furnished by the external source is utilised, the other half being wasted in heating the circuit. Jacobi's law does not, however, state that no motor, however perfect in itself, can convert more than 50 per cent. of the electric energy supplied to it into actual work. Dr. Siemens showed, some years ago, that a dynamo can be in practice so used as to give out more than 50 per cent. of the energy of the current. It can work more efficiently if it be not expected to do its work so quickly. Dr. Siemens has, in fact, proved that if the motor be arranged so as to do its work at less than the maximum rate, by being geared so as to do much less work per revolution, but yet so as to run at a higher speed, it will be more efficient; that is to say, though it does less work, there will also be still less electric energy expended, and the ratio of the useful work done to the energy expended will be nearer unity than before. Hence, when rate of working without regard to economy is the main consideration, Jacobi's law must be applied; but when economy has also to be considered this law does not apply. In this case $\frac{e}{E}$ must be as large as possible, and at the same time $(E - e)$, the measure of the energy lost as heat, must be as small as possible. This can only be the case when E and e are both large. In other words, it is an economy to work at high electromotive force. The importance of this matter, first pointed out by Siemens and later by Marcel Deprez, cannot be over-rated.

But how shall we obtain this high electromotive force? One very simple expedient is that of driving both generator and motor at higher speeds. Another way is to wind the armatures of both machines with many coils of wire, having many turns. This expedient has, however, the effect of putting great resistance into the circuit. This circumstance may, nevertheless, be no great drawback if there is already a great resistance in the circuit; as, for example, the resistance of many miles of wire through which the power is to be transmitted. In this case doubling the electromotive force will not double the resistance. Even in the case where the line resistance is insignificant, an economy is effected by raising the electromotive force. For, as may be deduced

from the equations, when $(E - e)$ is kept constant, the effect of doubling the electromotive force is to double the efficiency when the resistance of the line is very small as compared with that of the machines, and to quadruple it when the resistance of the line is very great as compared with that of the machines. It is, in fact, worth while to put up with the extra resistance, which we cannot avoid, if we try to secure high electromotive force by the use of coils of fine wire of many turns. It is true that the useful effect falls off, *cæteris paribus*, as the resistance increases; but this is much more than counterbalanced by the fact that the useful effect increases in proportion to the square of the electromotive force.

In the recent attempt of M. Marcel Deprez to realise these conditions in the transmission of power from Miesbach to Munich, through a double line of telegraph wire, over a distance of thirty-four miles, very high electromotive forces were actually employed. The machines were two ordinary Gramme dynamos, the magnets being series-wound similar to one another; but their usual low resistance coils had been replaced by coils of very many turns of fine wire. The resistance of each machine was consequently 470 ohms, whilst that of the line was 950 ohms. The velocity of the generator was 2,100 revolutions per minute; that of the motor, 1,400. The difference of potential at the terminals of the generator was 2,400 volts; at that of the motor, 1,600 volts. According to Professor von Beltz, the President of the Munich Exhibition, where the trial was made, the mechanical efficiency was found to be 32 per cent. M. Deprez has given the rule that the efficiency $\frac{w}{W}$ is obtained in the case where two identical machines are employed, by comparing the two velocities at the two stations. Or

$$\frac{w}{W} = \frac{n}{N},$$

where N is the speed of the governor, n that of the motor.

The latest effort of inventors, as applied to motors, has been to secure uniform speed with varying demands as regards work. Dr. Sylvanus Thompson, in his now famous Cantor Lectures on this subject, has dwelt on the importance of designing motors, not simply to work with the constant electromotive force supplied at the electric mains, but also to work at uniform speeds. It is highly important, for example, in driving a lathe, and indeed many kinds of machinery, that the speed should be regular, and that the motor should not "run away" as soon as the stress of the cutting tool is removed. Now we have already explained the methods by which M. Marcel Deprez and Professor Perry have solved the problem of getting a dynamo to feed a circuit with currents, at a constant electromotive force, when driven with a uniform speed. The solution to that problem we saw consisted in using certain combinations for the field magnets, which gave an initial magnetic field, independently of the actual current furnished by the dynamo itself. This problem may be applied conversely, and motors may be built with a combination of arrangements for

their field magnets, such that, when supplied with currents at a certain constant electromotive force, their speed shall be constant, whatever the work they may be doing. The one difficulty in the problem—and this is a mere matter for experiment and calculation—is to find the critical number of volts of electromotive force at which this will hold good. M. Marcel Deprez has, himself, constructed motors that run at a perfectly uniform speed, quite irrespective of the work which they may be doing. Whether the motor was lifting a load of five kilogrammes from the ground, or was letting this load run down to the ground, or ran without any load at all, the speed was the same. At the Paris Exposition Électrique of 1881 a large number of Deprez's motors were shown, running at uniform speed, and driving various machines—lathes. sewing-machines, etc.

Influence of Distance.—The total amount of heat generated in the circuit depends upon the resistance and strength of current. According to Joule's law the amount of heat generated is directly proportional to the resistance and the square of the current. If, for instance, the primary machine is three or four times the distance from the secondary machine, other conditions being equal, three or four times as much heat will be produced in the wires, and the amount of the transmitted work will diminish. But the conducting resistance is also inversely proportional to the cross section of the conductor; if, therefore, no energy is to be lost by doubling the distance, the conductor must have double the cross section; in other words, to double the distance without diminishing the current delivered to the motor, we must multiply the weight of the conducting wires by four, to treble the distance we must take nine times the weight of material, and so on. If the distance between the two machines is very great, this means is commercially impracticable, as the capital required for the material would be in no proportion to the result obtained.

The amount of heat depends further upon the strength of current. We can make the former constant in spite of the 4-, 9-, 16-fold increase in the length of the conductor, when we diminish the current to one-half, one-third, or one-fourth of its original strength. Again, the strength of current in the total circuit of the combined machines is equal to the difference of the primary and opposition currents; this difference becomes smaller as the difference of the electromotive forces of both machines becomes smaller, which can be brought about by diminishing the difference of the number of revolutions per minute in both machines. If, however, much work has to be done at long distances, by a small difference of rotation in the two machines, the electromotive forces of both machines have to be increased. This increase can be brought about either by increasing the number of revolutions, or by increasing the coils of the armature, or lastly by increasing both revolutions and coils. Theoretically, therefore, we may transmit any power we please to any distance by using any given system of conductors, as for instance, simple telegraph wire for the leads. The experiments made, however, up to the present have encountered practical difficulties not easy to overcome. The reason for this is, that on the one hand,

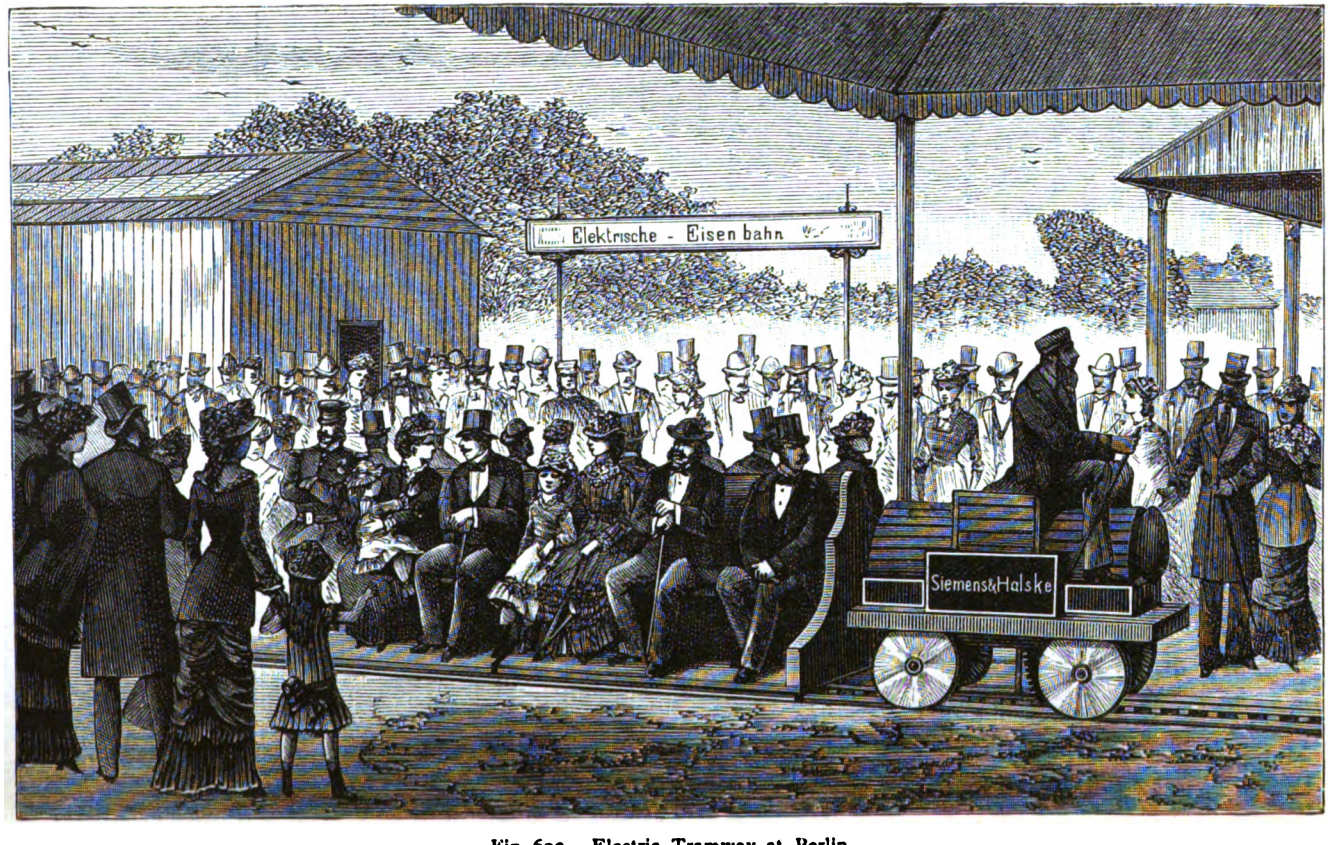


Fig. 602.—Electric Tramway at Berlin.

the number of revolutions cannot be increased beyond a certain limit, when the machine is not to be worn out rapidly; and on the other hand, the E. M. F. can only be increased to a certain limit, as the insulation would give way when the potentials used are too high, and the result would not only involve a loss of current, but also endanger the machines themselves. The practical use of the electric transmission of power is therefore restricted to moderate distances and moderate power.

In what, then, consists the advantage of electric transmission? First a motor is required for the primary machine, then a secondary machine, and the leads which connect the two machines are also sources of considerable expense. Why not allow the primary motor to do the work direct? If it be possible to employ the motor at the place required, it certainly would be cheaper and better to do so; but if it be impossible to bring the motor to that place at all, the work itself cannot be done without the intervention of some means of transmission. The transmission of power by means of tubes for compressed air, steam, or water, or by means of belting, etc., is only practicable for very short distances, and even for these short distances is very expensive. We will now give a series of examples of the cases in which electricity is employed for the transmission of power.

ELECTRIC RAILWAYS.

The most important applications of electric transmission of power are, at present, the electric railways. Shortly after the invention of electro-magnetic machines, Stratingh and Becker, of Gröningen (1835), and Botto in Turin (1836), constructed a magneto-electric carriage. Several others constructed similar apparatus, but as none of them were of much commercial value, we shall not go into further details respecting them. The first successful experiment was made with the electric railway exhibited by Siemens and Halske, during the Industrial Exhibition in Berlin, 1879. The railway at the Berlin Exhibition was 300 metres long. The rails formed a closed oval, so that the train returned to the point from which it started when the whole oval had been traversed. The train (which is shown in Fig. 602) consisted of an electric locomotive, and a platform upon wheels. Figs. 603 and 604 show the locomotive in section. It consists of a square frame on wheels; upon this frame is fastened a Siemens machine, in such a manner that the axis of rotation is parallel to the rails. The rotation of the armature is transmitted by the toothed wheels *l*, *t*, *v* and *x*, to the wheels of the locomotive. The current from the primary machine was conveyed to the secondary machine by means of the rail N, which was insulated from the earth, and placed between the two rails which support the train. Upon this middle rail slides the rubber T, which conveys the current to the secondary machine upon the locomotive. The same experiment was repeated with equal success at different other Exhibitions, as, for instance, Frankfort. In 1880 an electric railway was shown during the Exhibition of Vienna, by Egger, in which the middle rail was left out, one of the rails

representing the direct wire, and the other rail representing the return wire. In 1881 the first permanent electric railway was opened for the public; this is the railway constructed by Siemens and Halske at Lichterfelde.

An electric railway has been in use since 1880 at the works of M. Duchesne-Fournet, at Breuil en Auge (Calvados). In this large bleaching establishment machines have been used for some time for supplying current to the glow lamps, with which the establishment is lighted. Clovis Dupuy, the engineer of the establishment, resolved to utilise these machines during the day. The chemical processes which the linen has to undergo are so arranged that

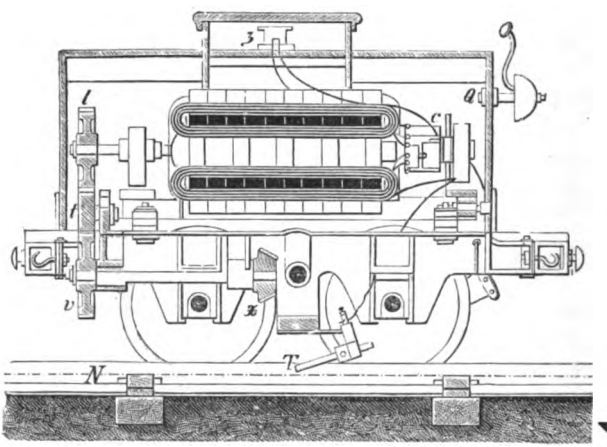


Fig. 603.

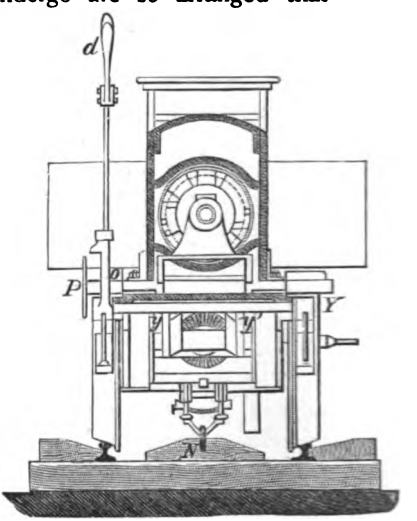


Fig. 604.

Siemens and Halske's Electric Locomotive.

between every two treatments the linen has to be exposed to the air in the meadows for five or six days. Much labour, time, and money had to be expended when the linen was taken out, arranged, and brought back by hand; and hot-air or steam-engines could not be employed for this purpose, on account of the smoke and dust. Dupuy, therefore, constructed an electric railway, by using accumulators; the reason for not using the machine currents directly was, that the construction of the leads over damp meadows would have met with many difficulties. The installation is arranged as follows:— The rails have a total length of 2,040 metres, covering an area of about 15 hectares. The rolling-stock consists of the locomotive, the carriage for the batteries, and the carriages intended for the linen. The battery carriage bears the accumulators, of which there are six packed in baskets; each of these Faure accumulators weighs 8 kilogrammes, and it takes about seven or eight hours to charge them; for this purpose the same Gramme machines are used as are used in the evening to feed the glow lamps. The locomotive in Fig. 605

consists of a carriage containing a Siemens machine, which obtains current from the accumulators; the current is used partly for the wheels of the locomotive, and partly for the rollers and shafts which haul in the linen. By means of the levers (on the right-hand side of the figure) the locomotive can be made to stop, slacken or increase its speed; and power can be applied as required either to the wheels, or rollers and shafts. The locomotive lifts a weight of 935 kilogrammes, and draws, besides the accumulator carriage, which

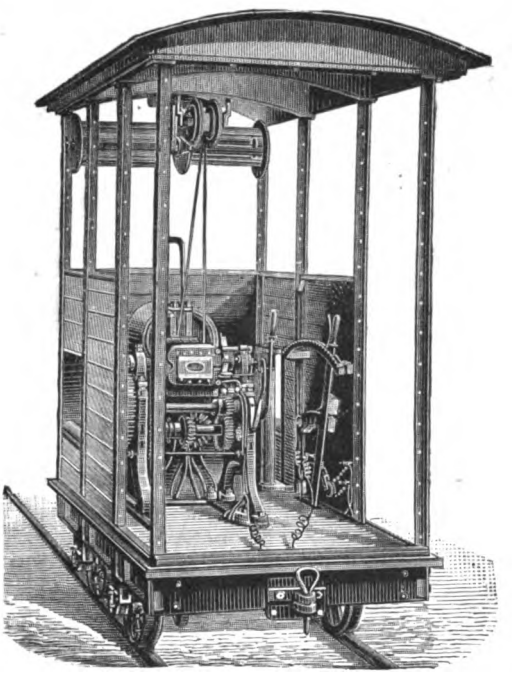


Fig. 605. – Dupuy's Locomotive.

weighs 700 kilogrammes, six other carriages, each of which, when full, weighs 800 kilogrammes; that is, a total load of 6,400 kilogrammes. The train in Fig. 606 is represented hauling in linen, while moving with a velocity of 12 kilometres per hour. By means of this arrangement 125 metres of linen can be collected in forty-eight seconds, or 500 metres in thirty-five minutes: a labour which was formerly done by seven persons in from four to five hours. Although, under exceptional conditions, as in the present instance, accumulators might be used with advantage, yet for most practical purposes the machine currents are used direct.

The Lichterfelde Railway, constructed by Siemens and Halske, which connects the Lichterfelde station with the Army Training School, has a length

of 2½ kilometres. The primary machine, with its steam-engine, is placed at Lichterfelde. Each carriage carries a secondary machine with it. The carriages

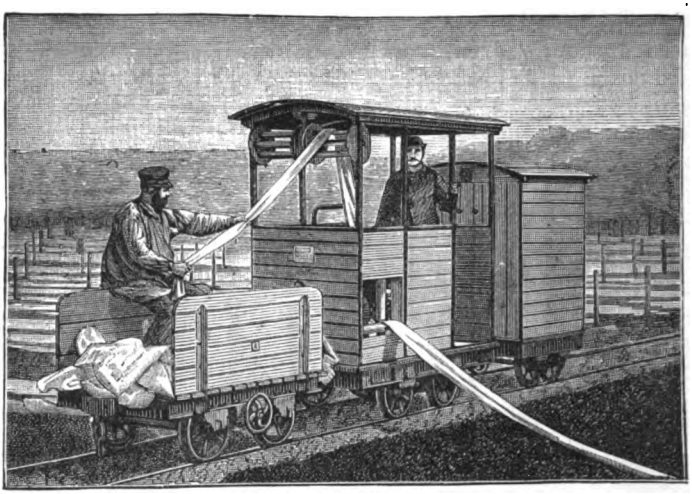


Fig. 606.—Dupuy's Electric Tramway.

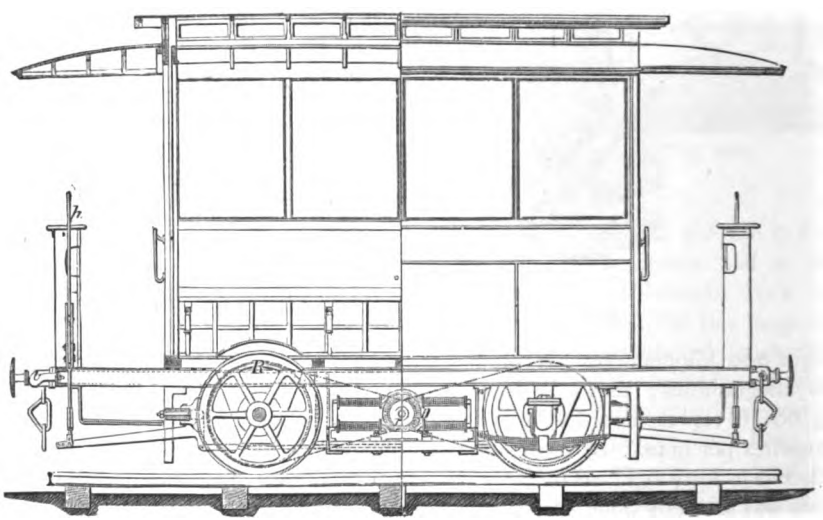


Fig. 607.—Carriage on the Lichterfelde Railway.

resemble tram-cars (Figs. 607 and 608), and the apparatus is placed at D. The secondary machine is so arranged that its axis of rotation is parallel to the axes of the wheels of the carriage. The rotation is transmitted by means of so-called

Jarolimek cords, and by the wheels R. Current is made or broken by turning a lever, and may be weakened by inserting resistances. The insertion and taking out of resistance is sufficient for the regulation of the speed of the carriages. Every secondary machine, as we have already mentioned, becomes a generator of counter-currents when in motion; a slow rotation of a secondary machine produces a weak, while rapid rotation produces a strong opposition current. A considerable force is necessary for starting the carriage; at this moment the secondary machine does not rotate at all, and consequently no opposition current is produced; as soon as the carriage begins to move, the secondary machine commences to generate opposition currents. The speed of the carriage will become uniform as soon as the difference between the primary and secondary currents has become constant. If the carriage has to ascend a hill more power will be required, and the rotation of the secondary machine will diminish; the reverse takes place when the carriage descends, the secondary machine begins to rotate more rapidly, and its current opposes the primary current. The leads by which the connection of the primary machine with the secondary machine is brought about are the rails themselves, which rest upon wooden sleepers above the ground, except where they cross. The several rails are connected by means of elastic copper strips, so as to make sure of an uninterrupted conductor.

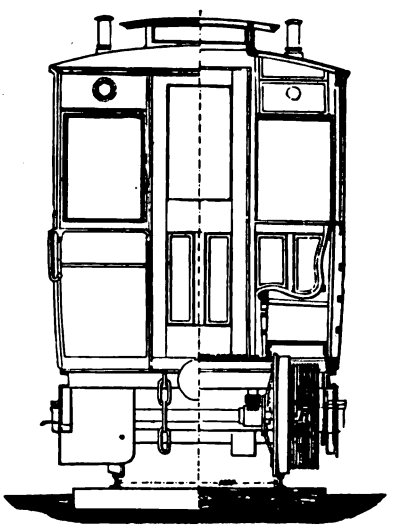


Fig. 608.—Carriage on the Lichterfelde Railway.

The current flows from one of the rails into the iron ring which surrounds the wheel disc, and from here to a metal box, which is fastened to the wheel-axis; upon this slides a spring, which is really a continuation of one of the poles of the secondary machine. The current from the other rail flows into the second wheel in the same way. This method of conveying the current could not be adopted for streets, as the contact with both rails might prove dangerous to animals and men. The ordinary speed of the carriage is 20 kilometres an hour; it can, however, go at a rate of from 35 to 40 kilometres when full, *i.e.* with twenty-six persons in it. From the 16th of May, 1881, to the 4th of January, 1882, only one carriage was used. At this time it was thought doubtful whether more carriages than one could be used; theoretically, however, it seemed possible, and was soon proved to be practicable. With double the power, and having the secondary machines joined parallel, the two carriages move with all the uniformity that can be desired.

The Electric Railway, Mödling-Brühl, a portion of which was in use during the winter of 1883 and 1884, and which now has a length of 3 kilometres, has the leads and return leads separate from the rails. The leads consist of iron tubes H and R in Figs. 609 and 610, which are open at the lower side, and supported by cables K and insulators J J. The insulators for the

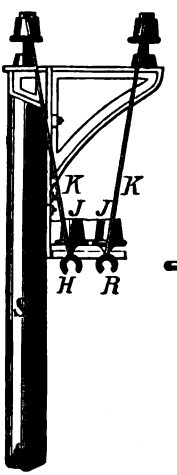


Fig. 609.
(*End Elevation.*)

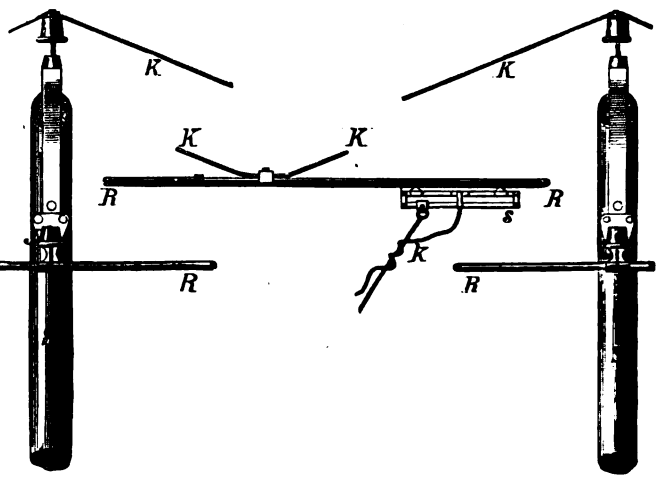


Fig. 610.—The Tubes and Cables of the Mödling-Brühl Line.
(*Side Elevation.*)

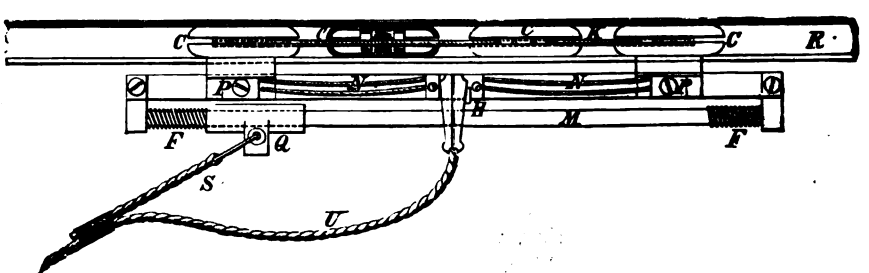


Fig. 611.—The Contact Boats.

cables, as well as the insulators for the tubes, are fastened by means of iron supports to the wooden column S. The leads are connected with the secondary machines in the carriage by means of the boats S, which slide in the tubes. Each boat is connected by means of a cord K to the carriage, and is pulled along with it. The arrangement is shown in Fig. 611. R is the tube in section throughout its length. C C are the four contact pieces, of which the sliding boat consists. In order that the pieces may make good contact with the tube, each of them consists of two basins, which are pressed against the sides of the tube by springs,

which are inside them. These contact pieces are connected with each other by means of the cable K, which consists of flexible copper wires. The first and last contact pieces C have prolongations P P, which protrude from the slit of the tube, and are firmly fastened to the elastic rod M; upon this slides Q, to which the rod S is fastened. To ease off the sudden pull of the ropes, a spiral spring is placed between Q and the projection. The current is conveyed from the contact boat by means of the cable U, which is fastened to H; the latter is connected with the boat by means of the copper rods N N, and the protruding pieces H. By dividing the contact boat into four pieces, and by using very elastic steel for the rod M, it is possible to pass curves of very small radius. Every carriage or train (for sometimes three carriages are fastened together) has two of such contact boats, of which the one slides in the tube which conveys the current, and the other in the returning tube.

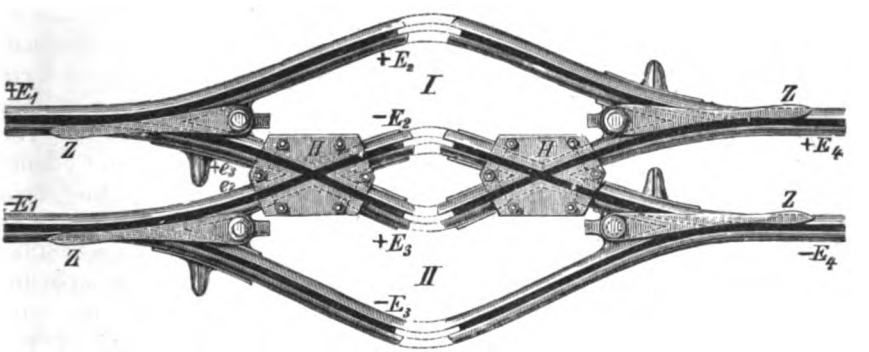


Fig. 612.—The Points.

As this railway has only a single line, it was necessary to construct points for allowing trains to pass each other. These, as constructed by Siemens and Halske, are shown in Fig. 612. When the positive lead + E arrives at the points, it divides into two portions + E_2 and + E_3; the negative lead − E_1 is similarly split up into the branches − E_2 and − E_3. At H the leads cross each other, and a short circuit would be produced, which would exclude the secondary machine of the carriage if the leads were to touch each other, and they are therefore so arranged that + E_3 and − E_2 are not in direct communication with each other. To prevent interruption in the portions + e_3 and + E_3 on the one hand, and − e_2 − E_2 on the other, they are connected with each other by means of metal bars, which are arranged inside the wooden piece H, and are not visible in the drawing. Where the tubes + E_1 and − E_1 divide, the tongues Z are placed, and held in the position shown in the drawing, by means of springs. The contact boats of each carriage approaching from the left will have to slide in the tube-couple I, because the tube-couple II is closed by means of Z. Every carriage approaching from the right will have to slide its contact boat through the tube-couple II.

If now, for instance, the carriage from the right continues its course, the contact boats enter the tubes + E_3 and − E_3; they then press upon the tongues z z, from behind, pushing them sideways, and allowing the carriage to continue its journey on + E_1 and − E_1. As soon as the last contact piece has left the tongues the latter swing backwards into their former position. The carriages for the primary and secondary machines are constructed like those of the Lichterfelde Railway. A 12 horse-power locomotive, and also a 120 horse-power fixed engine, are in use.

The Portrush Railway.—The Electric Railway at Portrush, in Ireland, is of great interest, and as here the force of a waterfall is utilised, we will treat it at length, and use it for illustration of the theory. The machinery, represented in Fig. 613, is described in *La Lumière Électrique*, 1883, and *The Electrician* of April 21st, 1883. In the summer of 1881, Mr. W. A. Traill, late of H.M. Geological Survey, suggested to Dr. Siemens that the line between Portrush and Bushmills, for which Parliamentary powers had been obtained, would be suitable in many respects for electrical working, especially as there was abundant water-power available in the neighbourhood. Dr. Siemens at once joined in the undertaking, which has been carried out under his direction. The line extends from Portrush, the terminus of the Belfast and Northern Counties Railway, to Bushmills, in the Bush Valley, a distance of six miles. For about half a mile the line passes down the principal street of Portrush, and has an extension along the Northern Counties Railway to the harbour. For the rest of the distance the rails are laid on the sea side of the county road, and the head of the rails being level with the ground, a foot-path is formed the whole distance, separated from the road by a kerb-stone. The line is single, and has a gauge of three feet, the standard of the existing narrow-gauge lines in Ulster. The gradients are exceedingly heavy, being in parts as steep as one in thirty-five. The curves are also in many cases very sharp, having necessarily to follow the existing road. There are five passing-places in addition to the sidings at the termini and at the carriage depôt. At the Bushmills end the line is laid for about two hundred yards along the street, and ends in the market-place of the town. It is intended to connect it with an electrical railway from Dervock, for which Parliamentary powers have already been obtained, thus completing the connection with the narrow-gauge system from Ballymena to Larne and Cushendall. About 1,500 yards from the end of the line there is a waterfall on the river Bush, with an available head of 24 feet, and an abundant supply of water at all seasons of the year. Turbines have been erected, and the necessary works executed for employing the fall for working the generating dynamo machines, and the current is conveyed by means of an underground cable to the end of the line. Fig. 613 represents the machine-house and the waterfall which supplies the natural motive-power. The primary generators (Siemens machines) receive their power from the two Alcott turbines, each of which generates 50 H. P. for 225 revolutions. The water at the higher level is led into a wooden aqueduct 2 7 metres, or 9 feet broad, and thus conveyed to the turbines through the cylinders shown in the

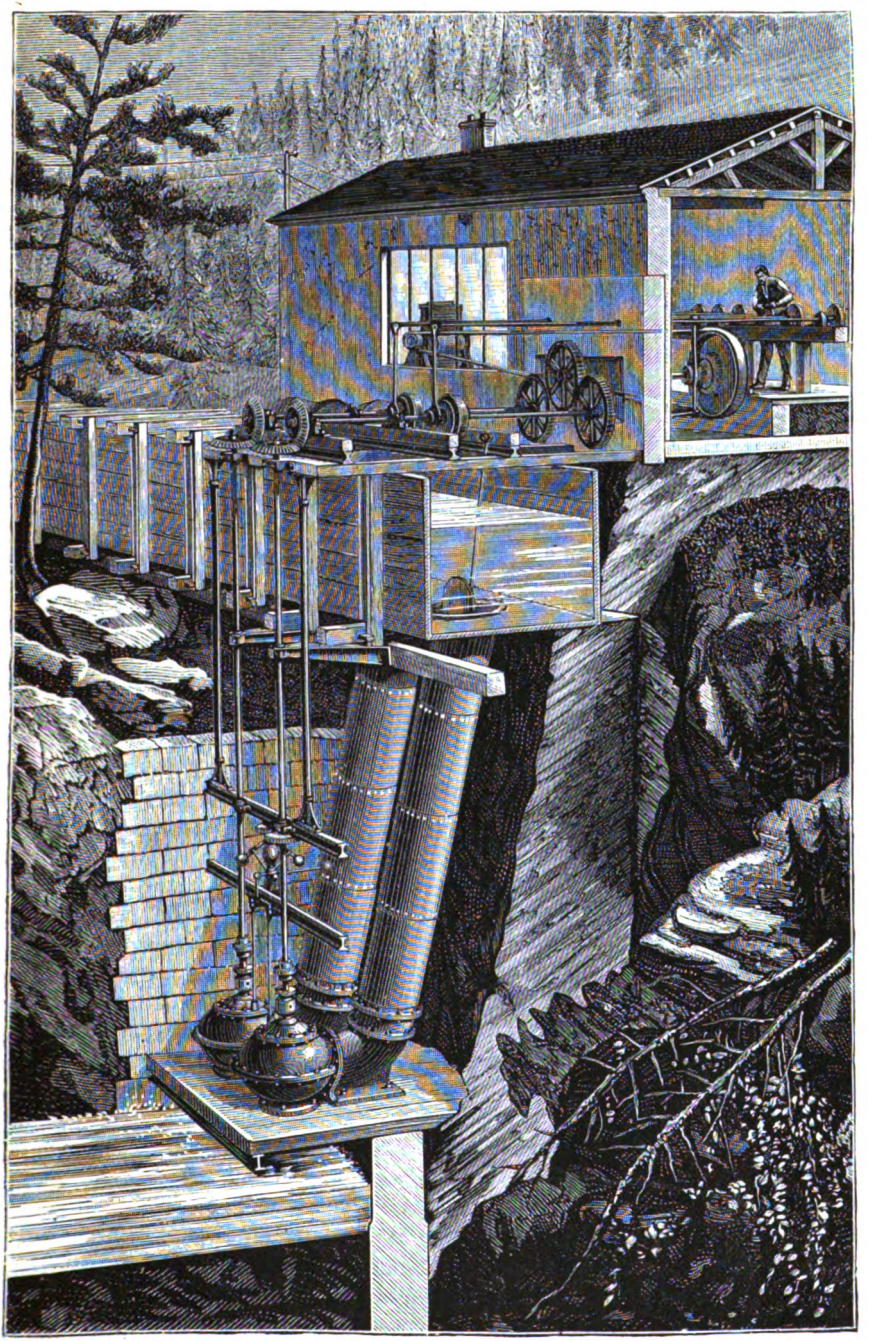


Fig. 613.—The Turbines at Portrush.

figure, which are 1·05 metre, or 3½ feet in diameter. The speed of the turbines is automatically regulated by means of a Watt governor. It is possible to influence the regulator from the machine-house, so as to alter the rate which is automatically maintained. The shafts of the turbine carry bevelled-toothed wheels, which gear with similar wheels on horizontal shafts. At the other ends of these shafts are ordinary toothed wheels, that by their joint action keep in rotation a third wheel, which conveys the power by means of ordinary shafting to the Siemens generator within the machine-house, and which may be seen through the window in the drawing. At first the line was worked by a small steam-engine placed at the carriage depôt, at the Portrush end. The whole of the constructive works have been designed and carried out by Mr. Traill, assisted by Mr. E. B. Price.

The system may be described as that of a separate conductor. A rail of tee-iron, weighing 19 lbs. to the yard, is carried on wooden posts boiled in pitch, and placed 10 feet apart, at a distance of 22 inches from the inside rail and 17 inches above the ground. The rail comes close up against the fence at the side of the track, thus forming an additional protection. The conductor is connected by an underground cable to a single shunt-wound dynamo machine, placed in the engine-shed, and worked by the turbines, or formerly by a small agricultural steam-engine. The current is conveyed from the conductor by means of two springs made of steel, rigidly held by two steel bars, placed one at each end of the car, projecting about six inches from the side: since the conducting rail is iron, while the brushes are steel, the wear of the latter is exceedingly small. In dry weather they require the rail to be slightly lubricated, in wet weather the water on the surface of the iron provides all the lubrication required. The double brushes placed at the extremities of the car enable it to bridge over the numerous gaps which necessarily interrupt the conductor, to allow cartways into the fields and commons adjoining the shore. When the car arrives at one of these gaps the front brush leaves the rail, but since the back brush still touches the rail the current is not broken. Before the back brush leaves the conductor the front brush will generally have reached again to it, so that the current is not interrupted. There are, however, two or three gaps too broad to be bridged over in this way. In these cases the driver will break the current before reaching the gap, the momentum of the car carrying it the 10 or 12 yards it must travel without power. The current is conveyed under the gaps by means of an insulated copper cable carried in wrought-iron pipes, placed at a depth of 18 inches. At the passing-places, which are situated on inclines, the conductor takes the inside, and the car ascending the hill also runs on the inside, while the car descending the hill proceeds by gravity on the outside lines.

From the brushes the current is taken to a commutator, worked by a lever, which switches resistance frames placed under the car, in or out, as may be desired. The same lever alters the position of the brushes on the commutator of the secondary machine, reversing the direction of rotation, in the manner shown

in the electrical lift (Fig. 622). The current is not as it were turned full on suddenly, but passes through the resistances, which are afterwards cut out in part or altogether, according as the driver desires to run at part speed or full speed.

From the machine the current is conveyed through the axle-boxes to the axle, thence to the tyres of the wheels, and finally back by the rails, which are uninsulated, to the generating machine. The conductor is laid in lengths of about 21 feet, the lengths being connected by fish-plates, and also by a double copper loop, securely soldered to the iron. It is also necessary that the rails of the permanent way should be connected in a similar manner, as the ordinary fish-plates give a very uncertain electrical contact, and the earth for large currents is altogether untrustworthy as a conductor, though no doubt materially reducing the total resistance of the circuit. The secondary machine is placed in the centre of the car, beneath the floor, and through intermediate spur-gear drives by a steel chain on to one axle only. The reversing levers and also the levers working the mechanical brakes are connected to both ends of the car, so that the driver can always stand at the front and have uninterrupted view of the rails, which is, of course, essential in the case of a line laid by the side of the public road. The cars are first and third class, some open and some covered, and are constructed to hold 20 people, exclusive of the driver.

Let us now put in a form suitable for calculation, the principles which Mr. Siemens has illustrated in a graphic form, and then show how these principles have been applied in the present case.*

Let L be the couple measured in foot-pounds, which the dynamo must exert in order to drive the car, and w the necessary angular velocity. Then by the theory of the motor L and w are constant. Taking the tare of the car as 50 cwt., including the weight of the machinery it carries, and a load of 20 people as 30 cwt., we have a gross weight of 4 tons. Assume that the maximum rate required is that the car should carry this load at a speed of 7 miles an hour on an incline of 1 to 40. The resistance due to gravity may be taken as 56 lbs. to the ton, and the frictional resistance and that due to other causes, say 14 lbs. per ton, giving, at a radius of 14 in., a total resistance of 280 lbs. The angular velocity at this radius corresponding to a speed of 7 miles an hour is 84 revolutions per minute. Hence $L = 280 \times 1\frac{1}{6} = 327$ foot-pounds, and

$$w = \frac{2\pi \times 84}{60}$$

in seconds and circular measure, in which the measure of one revolution per second is 2π.

If the dynamo be wound directly on the axle, it must be designed to exert the couple L corresponding to the maximum load when revolving at an angular velocity w, the difference of potential between the terminals being the available E. M. F. of the conductor, and the current the maximum the armature will safely

* See the *Electrician* for April 21, 1883.

stand. But when the dynamo is connected by intermediate gear to the driving wheels the product of L and w remains constant, although the two factors may be varied. In the present case L is diminished in the ratio of 7 to 1, and w consequently increased in the same ratio. Hence the dynamo with its maximum load must revolve at $84 \times 7 = 588$ revolutions per minute, and exert a couple of $327 \div 7 = 47$ foot-pounds.

Let E_1 be the potential of the conductor from which the current is drawn measured in volts, c the current in amperes, and E the E. M. F. of the dynamo. Then E is proportional to the product of the angular velocity, and a certain function of the current. For a velocity n, let this function be denoted by $f(c)$. If the characteristic of the dynamo can be drawn, then $f(c)$ is known.

We have then

$$E_1 = \frac{w}{n} f(c) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (1.)$$

If R be the resistance in circuit, by Ohm's law,

$$C = \frac{E - E_1}{R} = \frac{E - \frac{w}{n} f(c)}{R}.$$

And, therefore,

$$w = \frac{n(E - CR)}{f(c)} \quad \ldots \quad \ldots \quad \ldots \quad (2.)$$

Let a be the efficiency with which the motor transforms electrical into mechanical energy, then

Power required $= L w = a E_1 C = a C \frac{w}{n} f(c)$.

Dividing by w,

$$L = \frac{a C f(c)}{n} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (3.)$$

It must be noted that L is here measured in electrical measure, or adopting that unit given by Dr. Siemens, in the British Association address, in joules. One joule equals approximately ·74 foot-pound. Equation (3) gives at once an analytical proof of the principle, that for a given motor the current depends on the couple, and upon it alone. Equation (2) shows that with a given load the speed depends upon E, the electro-motive force of the main, and R the resistance in the circuit. It shows also the effect of putting into the circuit the resistance frames placed beneath the car. If R be increased until C R is equal to E, then w vanishes, and the car remains at rest. If R be still further increased, Ohm's law applies, and the current diminishes. Hence, suitable resistances are, first, a high resistance for diminishing the current, and consequently the sparking at make and break; and secondly, one or more low resistances for varying the speed of the car. If the form of $f(c)$ be known, as is the case with a Siemens machine, Equations (2) and (3) can be com-

pletely solved for w and C, giving the current and speed in terms of L E and R. The expressions so obtained are not without interest, and agree with the results of experiment.

Telpherage.—Another method available for the conveyance of goods, though not for passengers, is that of suspending the carriages from small wheels that run on an elevated rail, called a Telpher line, the whole method being called Telpherage. The system of Telpherage, invented by the late Professor Fleeming Jenkin, in conjunction with Professors Ayrton and Perry, has for its object the automatic electrical transport, along an overhead steel rope or rod, of goods, such as minerals, ores, slate, grain, roots, manure, or, in general, any goods easily divisible into parcels of from 2 to 5 cwt., at a cost greatly less than that of cartage, without driver, guard, signalmen, or attendants. The conception of propelling by electricity a continuous stream of light trains along an elevated *single* rail or rope was due to the late Professor Fleeming Jenkin; but, as he stated in his introductory address at the University of Edinburgh, he did not see his way to carry this conception into practice until he read the account of the electrical railway exhibited by Professors Ayrton and Perry at the Royal Institution, in 1882, when the idea of sub-dividing the rubbed conductor into sections, and providing an *absolute block* for automatically preventing the electric trains running into one another, was first publicly described. A combination between these three gentlemen was then effected, which led ultimately to the formation of the Telpherage Company, and to the series of experiments lasting for over two years, on Telpher lines erected at Weston, in Hertfordshire, on the estate of Mr. Pryor, the chairman of the company. Various devices were worked out, forming the subject of patents, which, together with the other patents of Professors Fleeming Jenkin, Ayrton, and Perry in Telpherage, previously taken out, are possessed by the present Telpherage Company. An opportunity soon offered itself of putting the merits of the method to an actual test. The Sussex Portland Cement Company needed a line for a short distance at Glynde, to convey clay to the railway, and as, through the experiments at Weston, matters had sufficiently advanced for the erection of commercial Telpher lines, and as a tramway or road would have much interfered with the grazing and hay-growing carried on in the fields at Glynde, and as, in addition, these fields are under water during the winter, Telpherage appeared to furnish the cheapest and most suitable mode of transfer. The line is nearly a mile long, and is composed of a double set of steel rods, each 66 feet long, three-quarters of an inch in diameter, and 8 feet apart, supported on wooden posts standing about 18 feet above the ground, as seen in our illustration (Fig. 614), which is from a photograph taken of the line just before it crosses the stream.

The principle of action is very simple. There are two lines of way, an up and a down line, supported on the cross-head of the posts. Each line is in pieces, and alternate segments are insulated. The problem to be solved is to maintain adjacent segments at a difference of potential, so that a train touching

two adjacent pieces may receive a current which will work a motor. All the insulated sections are electrically joined by cross-over pieces at the posts, and all the uninsulated sections are similarly joined. This gives an electrical system of conductors represented diagrammatically in Fig. 615, where D represents a dynamo, by which the two long conductors are maintained permanently at different potentials, as indicated by the signs + and – of each section. The

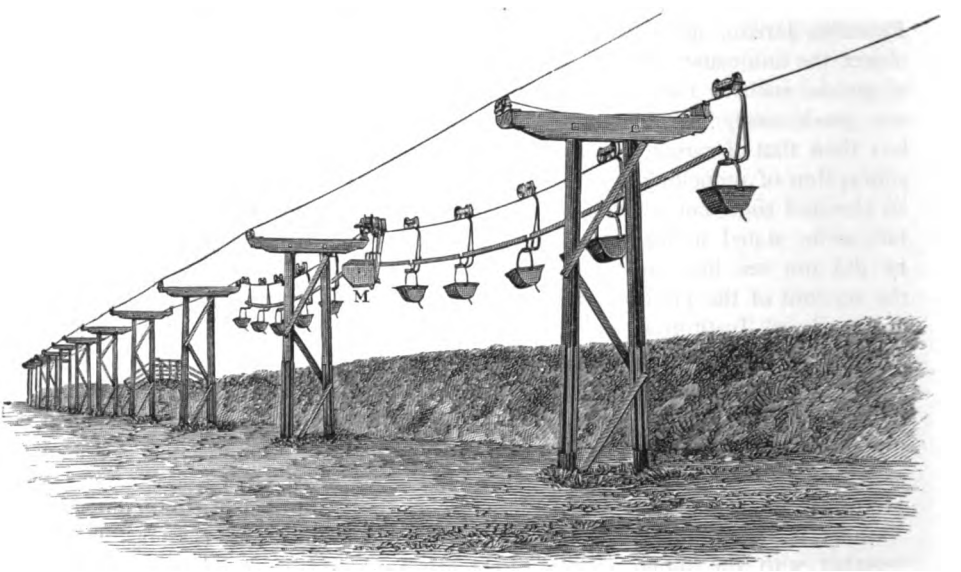


Fig. 614.—Glynde Telpherage Line.

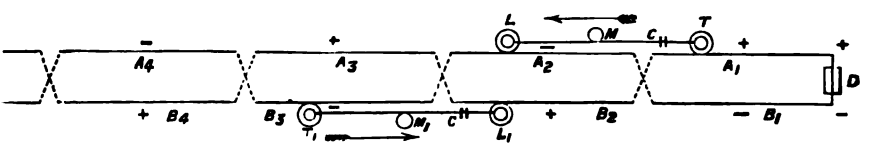


Fig. 615.—Principle of the Line.

wheels L and T, insulated from their trucks, are joined by a conductor which passes through a motor M. A current consequently passes from a + section to a – section whenever the train L T bridges over two sections; and this will always be the case except when, for a short length of about three inches, the wheels rest on an insulated gap-piece on the saddle of the posts. The current flowing round the motor drives a shaft at a very high rate of speed; 1,600 revolutions per minute is the normal rate adopted for the line at Glynde. This shaft is connected by suitable gearing to the driving wheels of the locomotive, which hauls along the train at a speed of about four miles per hour. The train

consists of a series of trucks, evenly and somewhat widely spaced, so as to distribute the load uniformly along the suspended rods. The train is either of the length of one span or two spans, consisting usually of a locomotive with five trucks in the first case, and a locomotive with ten trucks in the second case. This arrangement is adopted to neutralise the effect of the sag in the line as a resistance to the motion of the train. The initial source of power is the Ruston and Proctor engine, formerly used in the Weston experiments, and controlled by a Willan electric governor; this drives a Crompton 6 "unit" shunt-wound dynamo, D in Fig. 615. The maximum difference of potential is 190 volts; the current for one train is 8 amperes, two trains need 16 amperes, and so on.

The next point of interest to be noticed is the behaviour of the motor at different parts of the line. The motors will not receive equal currents at various parts of the line. They will not, therefore, unless otherwise governed, develop equal horse-power. The current flowing through each motor depends on three magnitudes: A, the electro-motive force between its terminals supplied by the line; B, the back electro-motive force due to the motor itself when running; and R, the resistance of the motor. Let the current through the motor be called C, then

$$C = \frac{A - B}{R}.$$

At different parts of the line A will vary, and even at one part of the line A will not be constant unless the currents in the line are constant. B is nothing when the train is at rest, and increases as the speed increases.

If the normal current be just enough to drive the train, we shall have too little at the far end and too much at the near end. There are two ways of dealing with this difficulty. As we have said, B (the back E. M. F. of the motor) is only constant when the speed is constant, but if the train be allowed to slacken speed B falls off. A larger current will then flow through the motor, increasing the couple exerted by that motor. Conversely, if the speed of the train is allowed to increase, the value of B also increases in almost direct proportion; the current through the motor would diminish, and the effort made by the motor would also diminish. If, therefore, the mechanical resistance of the several trains were constant, and the current allowed to distribute itself subject to no special regulation, the near trains would run a little faster and the far trains a little slower. But we have in addition to provide for very unequal mechanical resistance to the haulage of the train at different parts of the line—the train may be running up-hill, down-hill, or on a level, and all varying gradients must be provided for if we are to work the trains automatically.

This automatic governing of the speed of the trains is effected in two ways—first, there is a governor attached to each motor, which interrupts the electric circuit, and cuts off the power when the speed is too high; secondly, there is a brake which comes into action if the speed increases still further.

It is the duty of the governor, shown in Fig. 616, to distribute the power so as to solve this problem. The E. M. F. produced by the dynamo is made ample to provide a normal current through all the motors, which, if it flowed continuously, would do more than the necessary work at the normal speed of the motor. The governor cuts off the current from the motor for larger or shorter recurrent intervals according as more or less work is required. Thus on a moderate upward incline the current will be on for the whole time; on a steep downward incline it will be wholly cut off; on a level it will be on for, say, half the time, being taken on and off, say, five times per minute, for six seconds on each occasion. In this way the power received can be exactly fitted to the work required. This result is obtained by constructing the governor

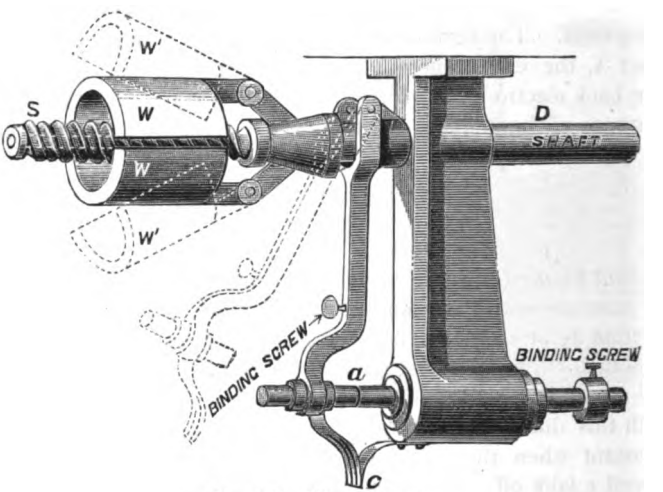


Fig. 616.—The Governor.

so that the diverging weights w w are in unstable equilibrium between two stops —flying out at about 1,750 revolutions per minute, and flying back at about 1,650. This is necessary to insure a sudden break of considerable magnitude in the electric circuit, to prevent the formation of a permanent electric arc when the circuit is broken. When the circuit is closed the current is conveyed across the metallic contact at *c*. When the weights fly out this contact is first broken, but no flash occurs because a connection of small resistance is maintained at *a* for a short time between two pieces of carbon, or between a rod of carbon and a rod of iron, by the rod which fits into the tube at the bottom of the apparatus being pressed outwards by a spring, and so made to follow the rod, which is attached to the moving arm, for a short distance, as the arm flies out into the dotted position. This contact at *a* is next broken, with the result of producing a brilliant electric arc for a fraction of a second, which is harmlessly employed in

very slowly consuming the carbon rod. This method of regulating the power has been experimentally tested with complete success.

The brake is shown in Fig. 617. It is simply a pair of weights w w, which, at the limiting speed, press wooden brake blocks B B against a fixed rim C with sufficient force to produce the required friction. At lower speeds the springs S S hold the blocks away from the rim. Very light diverging weights are sufficient, owing to the high speed.

It is claimed that the Telpher line will find its application in all cases where the traffic is sufficient to pay interest on a small outlay, and is insufficient to pay for the construction of even the cheapest form of railway. By employing electricity the following advantages are gained: The road is simpler and cheaper, as there are no pulleys or working parts, and no second rope is required; the maintenance is cheaper; there is nothing to oil, and no working parts to wear out; the direction of the electrical road can be changed as often as is desirable, so as to follow a winding direction, an object difficult of attainment even to a moderate extent with rope haulage; the gradients in the electrical road may be as heavy as one in eight, and these gradients may vary as frequently as is desired, which is not possible, except with complicated arrangements, in rope haulage; finally, the power required will be less, except in the simplest cases of rope haulage. In addition, the electric power can easily be "tapped" *anywhere* along the line, and used for working agricultural or other machinery simultaneously with the propulsion of the Telpher trains.

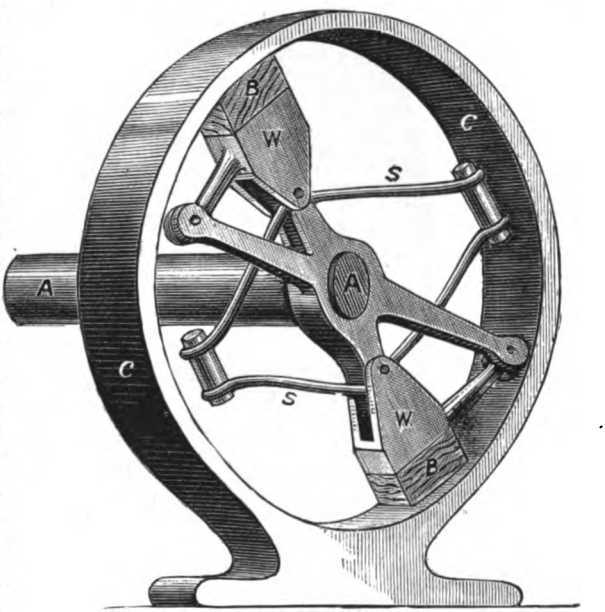


Fig. 617.—The Brake.

As compared with light steam railways, the Telpher lines have the following advantages: They are cheaper, requiring less metal than the lightest rails. No earthworks, bridges, culverts, drains, or fences are required. No land need be purchased. Much sharper curves can be employed. No attendant is required to accompany the trains. Telpher lines crossing a farm will not materially interfere with the cultivation of the land.

Mine Railways.—As the electric transmission of power is likely to become of great importance in mines, tunnels, etc., we will next describe the mine railway at Zaukerode, Saxony. This line has a length of 700 metres, and is 260 metres under the surface of the earth. The electric locomotive moves with a velocity of about 12 kilometres per hour, carrying a load of 8,000 kilogrammes in 10 carriages. The locomotive constructed by Siemens and Halske, shown in Fig. 618, has a length of 2·4 metres, a height of 1 metre, and

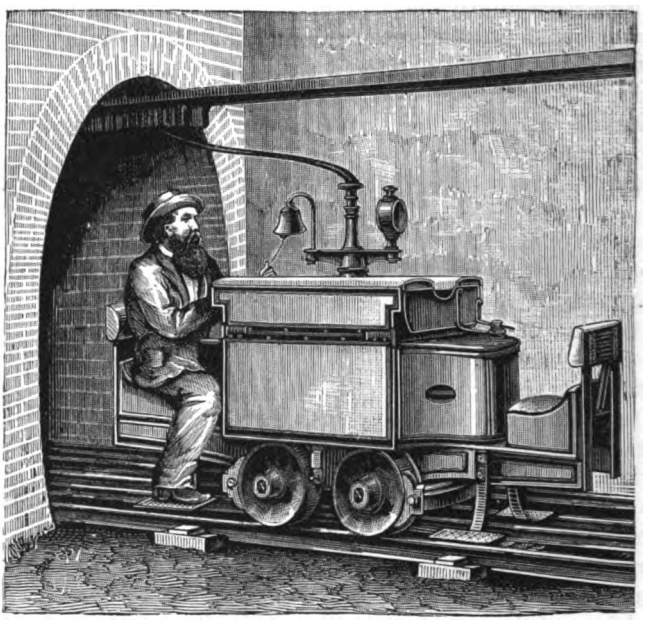


Fig. 618.—Mine Locomotive.

a breadth of only 80 centimetres. It weighs 1,550 kilogrammes. The gauge is only 56·6 centimetres wide. The rotation of the armature is transmitted to the wheels of the locomotive. A dynamo-electric machine, which is driven by a small cylindrical steam-engine, is placed outside the pit for the generation of the current. The current is conveyed by means of a cable to the T-shaped iron rails fastened to the ceiling of the gallery, and a contact carriage, which slides upon the T-shaped rails, conveys the current to the secondary or locomotive machine. The driver can make the machine go backwards or forwards by turning a lever. In the same pit a ventilator is in use, which is also worked by electricity.

An electric railway for the Hohenzollern mine, near Benthen, has also been constructed by Siemens and Halske, and the use of such lines in mines appears likely to extend.

MISCELLANEOUS INDUSTRIAL APPLICATIONS.

Boring Machines.—The utilisation of a flow of water for obtaining power for mining and tunnelling had been resorted to before electricity had furnished a means of transmission; so that on the perfection of electro-motive machines, the latter were at once applied for the conveyance of the power to the points of operation. During the construction of the St. Gothard Tunnel, the fall of the river Reuss was utilised in the following way: About a hundred paces from the mouth of the tunnel at Goschenen, turbines of 1,000 to 1,200 horse-power were worked for compressing air; which was conducted through a system of pipes, prolonged as the work advanced, to the boring machine. The greater the distance at which the borer operated, the less the yield of energy by the condensers. The reservoir of air compressed to seven atmospheres pressure returned 70 per cent. of the energy expended on it; a locomotive worked with compressed air returned 23 per cent.; but the boring machine returned only from four to eight per cent. of the energy.

Boring machines may be divided into percussion machines and rotation machines. A machine on the first principle, worked by electricity, has been constructed by Siemens, and a rotation boring machine has been constructed by Taverdon.

Taverdon's Electric Rock-Borer.—For borings in hard rocks, by the rotation machines, as a rule, diamonds are fixed in the borer, because steel points are not sufficiently durable. Leschot's front piece, for instance, consists of an iron tube having eight black diamonds, of which there are four fastened to the inside, and four to the outside. Taverdon solders the diamonds, and coats them with a layer of copper for the purpose. The borer is worked by electricity, as shown in Fig. 619. The boring machine and the motor are arranged upon separate frames on wheels. The borer is fastened to a nozzle, which can be moved along the bar to which it is fastened. The front piece is made to rotate by means of pulleys, arranged as shown in Fig. 620. The driving rope *a a* is not taken direct over the pulley *e*, which turns the borer, but has first to go over *b b'*, an arrangement which allows the borer to be turned without disarranging the driving rope. As motor or secondary machine, a Gramme machine is used, which has also to work a pump. Upon the same frame a vessel is placed which conveys water under pressure to the holes in order to wash away the loose sand.

Electric Punches.—The electric punch, by Deprez, is shown in Fig. 621. It consists, as it were, of a drawn-out Gramme ring, in which the iron cylinder is movable. A B consists of 80 flat solenoids or coils, about one centimetre thick, which are connected under each other and with the commutator in the same way as in a Gramme ring. The metal contact-pieces E D can be made to slide over the metal strips G F of the commutator, by means of the handle H I. The strip E can make any angle with D, and can be fixed in this position by means of

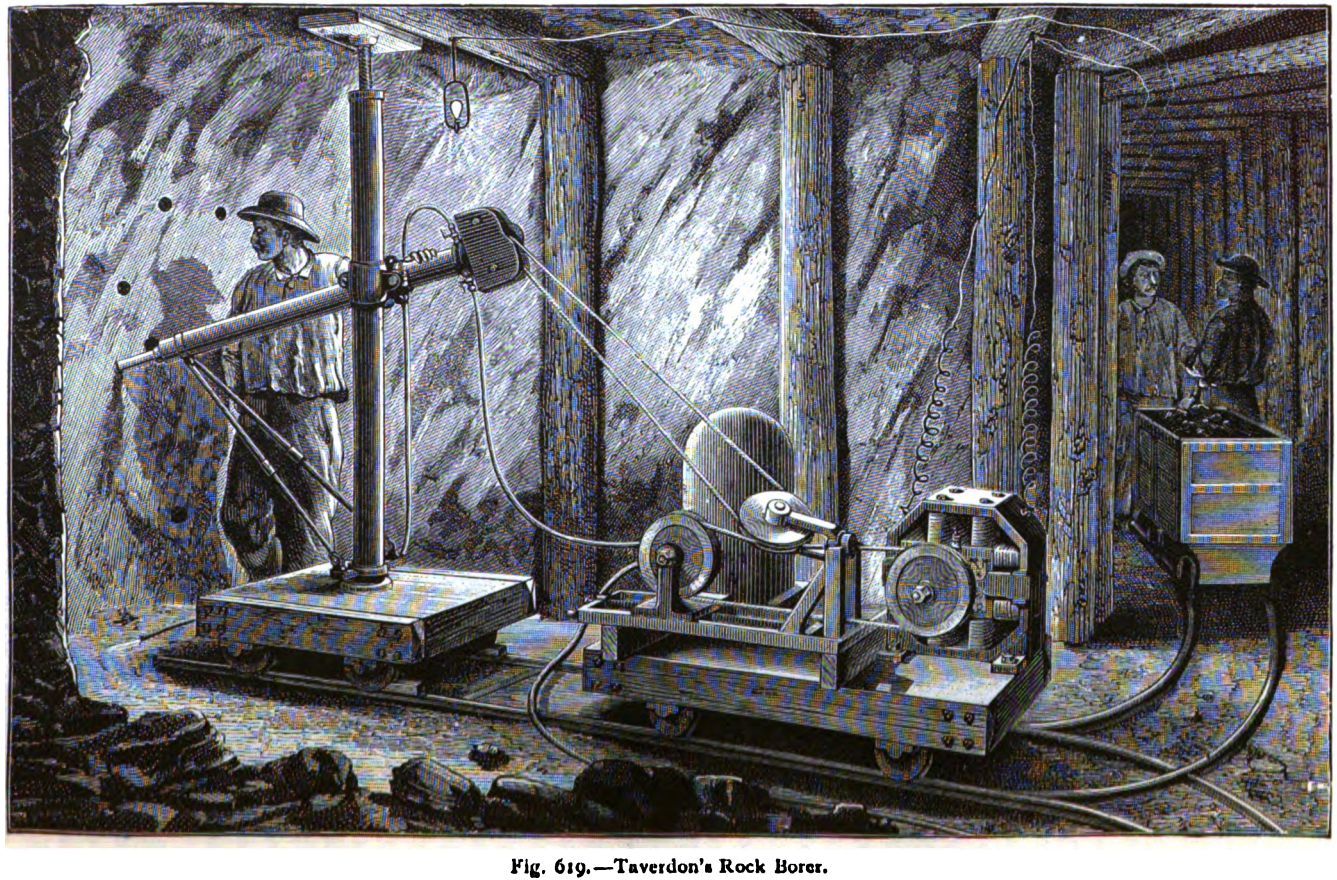


Fig. 619.—Taverdon's Rock Borer.

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a screw. If, for instance, between E and D there are ten contact strips, the current will pass through the corresponding ten solenoids or coils. If the current is sufficiently strong, the iron cylinder inside the solenoids will be suspended, and the cylinder will then move up or down, according to the direction in which the commutator is turned. Deprez has also constructed a punch, the iron core of which weighs 23 kilogrammes, giving an effect of 70

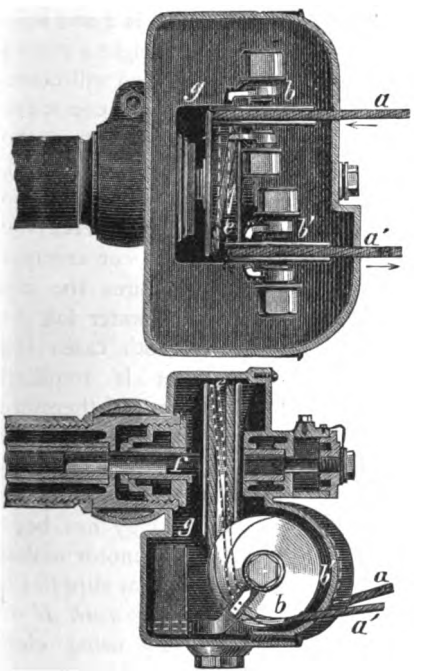


Fig. 620.—Taverdon's Rock-Borer.

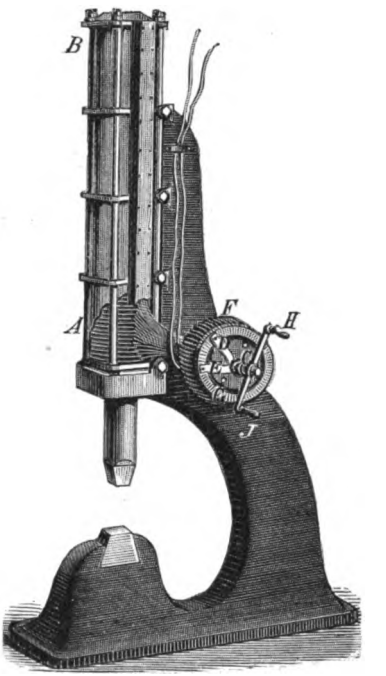


Fig. 621.—Deprez's Punch.

kilogrammes when a current of 43 amperes circulates through 15 coils. The current in the apparatus never varies in strength or direction, and the magnetism in the iron core also remains unaltered.

Electric Lifts.—The electric transmission of power is of great advantage for *lifts*, *cranes*, &c. In illustration of this, Uppenborn points out that at the Central Station, Hanover, there are several hydraulic lifts, each of which requires no more than two H. P. For charging the hydraulic accumulators a 40 H. P. steam-pump, however, is required. As a rule, only two lifts are used at a time. If electric lifts, instead of the hydraulic lifts, had been chosen, a 6 H. P. steam or gas engine would have sufficed, and the apparatus and working would have cost considerably less. Similarly, Hospitalier pointed out that by using hydraulic pressure for the working of cranes, there are certain disadvantages which might

be avoided by using electricity. At Marseilles, for instance, a steam-engine pumps water under a pressure of 55 atmospheres into a reservoir, from which the several cranes are fed, causing a loss of about 50 per cent. of energy, due to friction, leakage, &c. This loss, however, may increase to 80 per cent., as shown in the following case:—If a crane, whose maximum strength is 2,000 kilogrammes, has to lift this weight 4 metres high, the water pressure used will correspond to a work effect of $2{,}000 \times 4 = 8{,}000$ kilogramme-metres; but if the crane has to lift only 500 kilogrammes, the work effect will be $500 \times 4 = 2{,}000$ kilogramme-metres. But whatever the weight lifted may be, the construction of the hydraulic lift requires the use of the same quantity of water for the same elevation. In both cases the same quantity of water is required under the same pressure, and therefore assuming 50 per cent. to be lost in overcoming friction and other resistances in the second case, only $12\frac{1}{2}$ per cent. of the original energy has been utilised. Now an electric motor makes demands on the source that supplies it *in proportion only to the work it is called on to perform.* By using electricity, the secondary machine reacts upon the primary by producing opposition currents, and if the secondary machine has to do less work it will rotate more quickly, and generate a more powerful opposition current. The current in the total circuit therefore diminishes, and the primary machine requires less expenditure of energy. The reverse takes place when the secondary machine has to do considerable work.

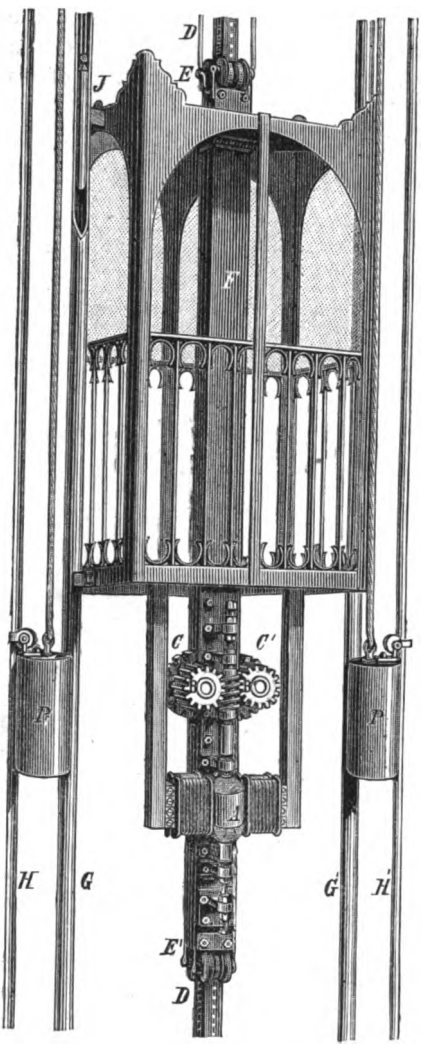


Fig. 622.—Electric Lift.

Hospitalier concludes that to realise the idea we have only to consider how to produce the current for the purpose, and how to convey the current to a number of the branches, so that the currents that traverse the different branches may vary with the requirements of the machines that are included in them. With

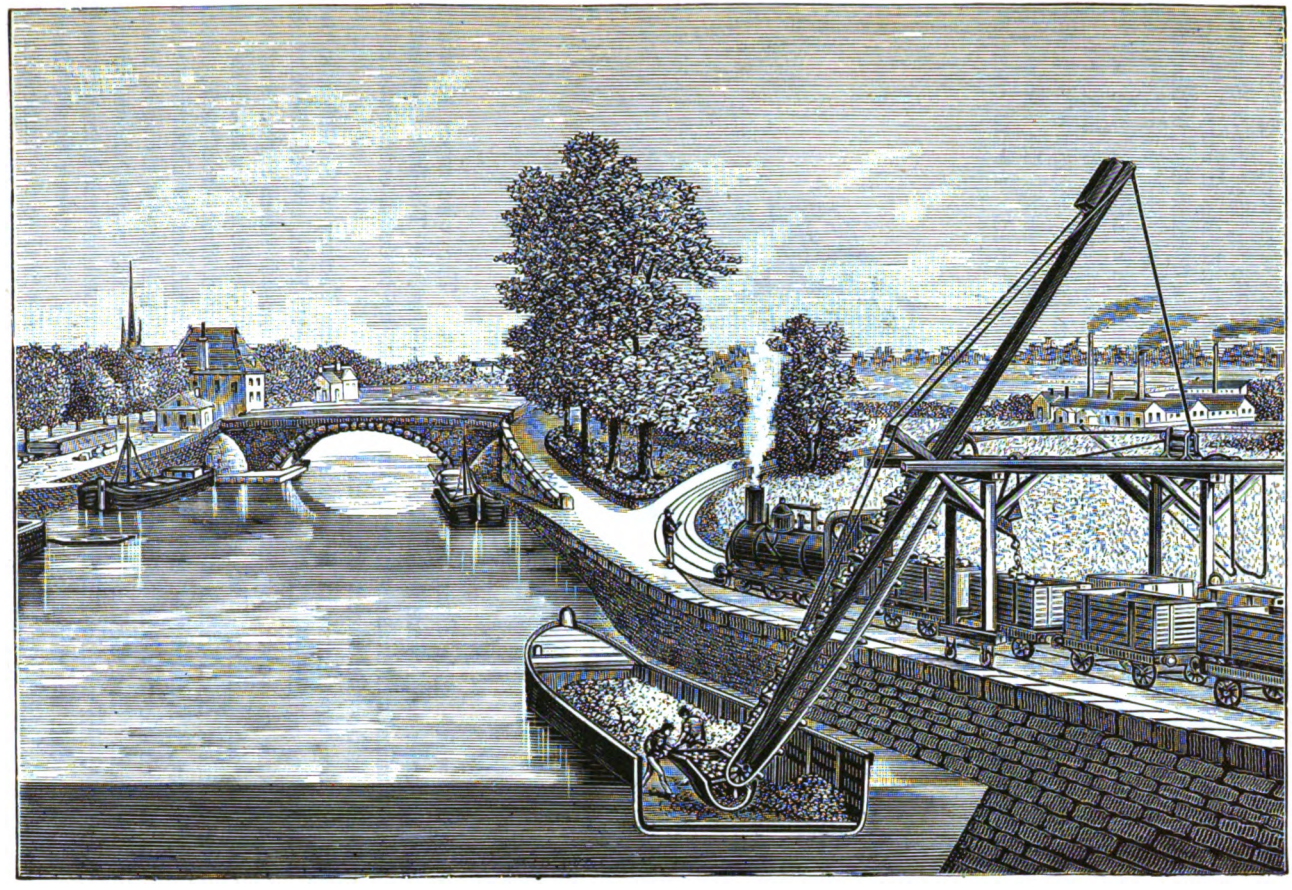


Fig. 623.—Electric Elevator at Sermaize Factory.

the invention of the compound machine, we believe this is no longer difficult. A lift was exhibited for the first time at Mannheim, in 1880, by the firm of Siemens and Halske; and a second lift was worked during the Exhibition at Paris. Underneath the lift, which is intended for carrying persons, is a dynamo-electric machine A, Fig. 622, the axis of rotation of which is placed vertically, and has an endless screw on one side, by means of which the wheels B B and C C′ are set in motion. The teeth of the latter catch into the cross-pieces of the ladder D D. E E′ are guiding pulleys, connected with the commutator by means of a lever, so arranged that the current can be caused to flow through the secondary machine in either direction, or may be entirely interrupted. P P are counter-

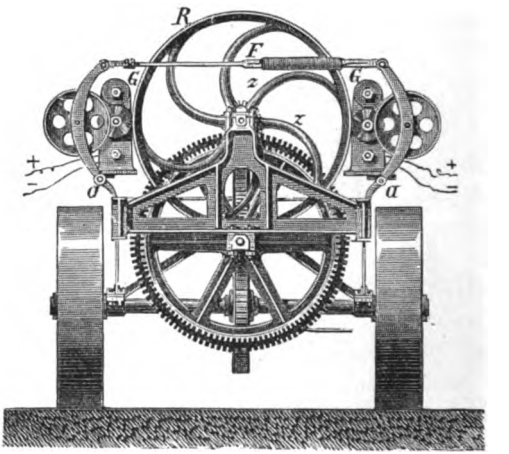


Fig. 624.—Electric Plough.

weights, which slide along the guiding bars G H. The wire ropes to which these counter-weights are fastened also convey the current. The lift is prevented by mechanical contrivances from rushing suddenly up or down, even if the ropes should break or the current be interrupted.

Fig. 623 represents an elevator used in the Sugar Factory of Sermaize, in the Department of Marne. The engineers, Chrétien and Felix, applied the electric transmission of power, by utilising an almost unused steam-engine and the machines for lighting. The greater portion of the beetroot consumed in this establishment is unloaded at the harbour of Sermaize, about 100 metres from the factory. Formerly the unloading was done by hand, but for about five years the electric elevator has been made use of, and has effected a saving of about 40 per cent. The elevator represents a kind of dredging engine, shown in the figure. For the motion of the drums and chains two Gramme machines are used, of which one, the primary, is placed at the factory, and driven by the steam-engine; and the other, the secondary machine, is fastened to the framework of the elevator.

The Electric Plough.—The steam-engine has also been used for working an *electric plough.* Two Gramme machines are placed upon frames on wheels, one frame being placed at one end of the field, the other frame at the other end. By means of wire ropes winding and unwinding round drums the plough is drawn across the field. Figs. 624 and 625 represent these motors. Upon the iron frames are the two Gramme machines G G, suspended about the horizontal axes *a a.* The axes of rotation of the two Gramme machines carry friction discs at their two ends, and are, along with these discs, pressed against the large friction wheels R R, by means of a connecting rod F. The friction wheels R R transmit their rotation by means of the wheels Z Z to the rope-drum S. By adjusting conical

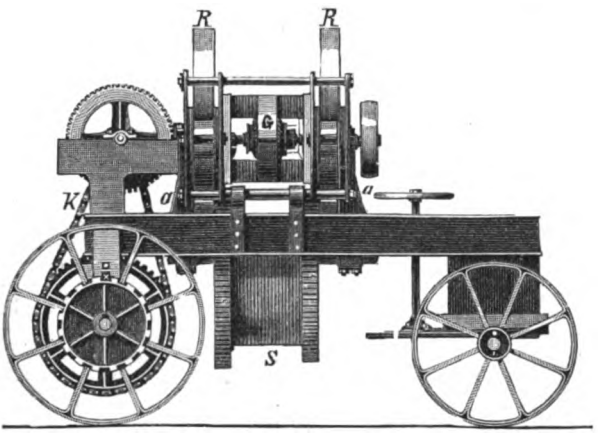


Fig. 625.—Electric Plough.

wheels, the rotation of the Gramme machines can also be transmitted to the wheels of the frame by means of the chain K. The rope-drum in this case would not be made to rotate, but the whole would be made to move in one or the other direction. The current for the secondary machine, placed upon the carriage as already described, is furnished by primary machines placed under cover, and driven by the stationary steam-engine.

Electric Brakes.—Many proposals have been made to use electric currents for stopping railway trains. Achard has made the electric brake his especial study, and L. Regray has given detailed descriptions of the experiments made with electric brakes by the French Eastern Railway Company, in *La Lumière Électrique*, 1883. To convey an idea of this application of the currents we will give a description of one of the arrangements. The construction of the electro-magnet, which sets the brake in action, is shown in Fig. 626. To the axis *c c'*, which moves in the supports T T, the electro-magnet, with its shoes *f f'*, is fastened upon brass pieces *a* and *b*. The ends *e* of its coils pass through bores in the axis *c c'* to the contact-pieces *g g'*. A Gramme machine is used as the

source of electricity, and, together with its motor, a Brotherhood machine, is placed on the locomotive. The arrangement and the manner of working of the magnet may be seen from Fig. 627. The supports T, in which the magnet M hangs, in front of the carriage axis A, are fastened to joints. When a current is sent through the magnet the shoes become powerfully magnetised, and the

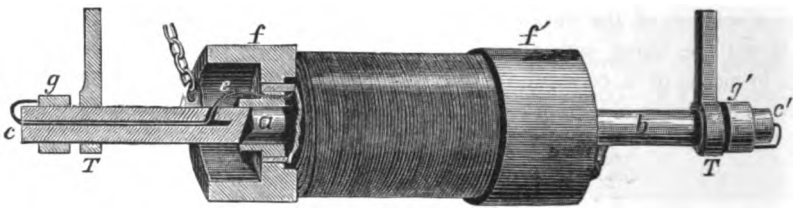


Fig. 626.—Electric Brake.

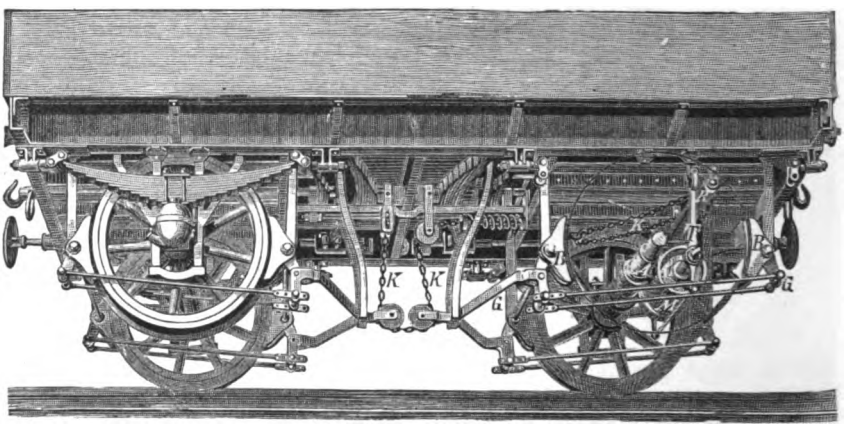


Fig. 627.—Electric Brake.

magnet will move towards the axis and stick to it; the magnet will now have to rotate, winding the chain K over the pulley R, and causing, with the help of connecting rods G G, the brakes B B to press against the wheels of the carriage. By means of springs the brakes can be removed from the wheels when desired.

SMALL ELECTRO-MOTORS AND THEIR APPLICATIONS.

By small electro-motors are meant those which do not yield more energy than 10 second-kilogramme-metres. Fig. 628 shows such a motor constructed by Deprez. This motor is a Siemens machine (compare Fig. 218), in which the cylindrical armature is parallel to the arms of the electro-magnets. This motor may also be used as a generator of electricity; and, when so used, has the effect

of three Bunsen elements. When he used the machine as a motor, driven by an element of 0·04 second-metre-kilogramme, Deprez obtained the following results:

Elements	2	3	4	5	8
Second-metre-kilogramme	0·2	0·45	0·75	1·1	1·8

The magnets of this model were 145 millimetres long, the poles of which were 33 millimetres distant from each other. The armature had a length of 60 and a diameter of 32 millimetres, and the whole apparatus weighed 2·85 kilogrammes. This motor was used during the Exhibition at Paris for the working of sewing-machines, with Deprez's system for the distribution of the current.

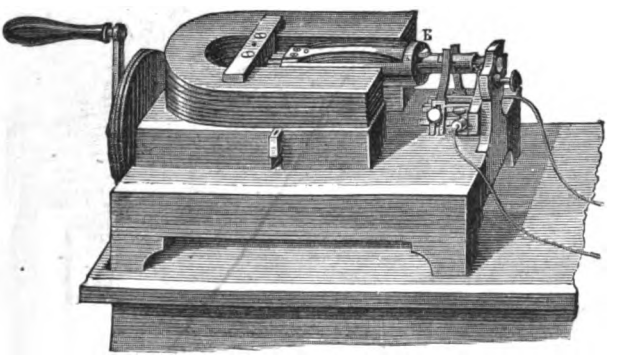


Fig. 628.—Deprez's Small Motor.

The motor by Trouvé also represents a small Siemens machine. The coil C, Fig. 629, is fastened upon a frame E, and has two pole-plates A A bent upwards. Between these a Siemens armature rotates. The current is conveyed through the screws F and H; at the opposite end a small fly-wheel is fastened to transmit the motion of the armature to other instruments. The armature here has spiral-shaped pole surfaces, to avoid the dead points during the rotation. Trouvé's motor may be used for driving a sewing-machine, a bicycle, or a small boat, the current of some chromic acid elements being allowed to pass through its coils. The arrangement of the motor for driving a boat is shown in Fig. 630.

Griscom's motor in Fig. 631 is used for working a sewing-machine. Fig. 632 shows a section of the same. The cylindrical armature A A is surrounded by the tube-shaped electro-magnet E E, which has its poles at N and S. A change in the direction of the current is brought about by the commutator C every half-revolution. The current coming from the battery B passes through the contact spring *f'*, and the left commutator segment, into the coils of the armature; from here through the right-hand commutator segment, and the

contact spring *f*, into the coils of the electro-magnets E E, and then back again to the battery. If the armature, owing to the attraction of dissimilar, and repulsion of similar poles, has approached the line *x y*, at the same time a change of the current takes place in consequence of the turning of the commutator, and with it a change of polarity, which causes the armature to continue its rotation in the same direction. Griscom's motor has a length of about 10

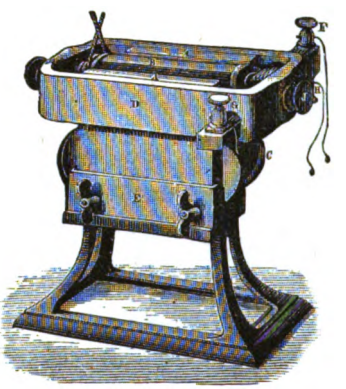


Fig. 629.—Trouvé's Small Motor.

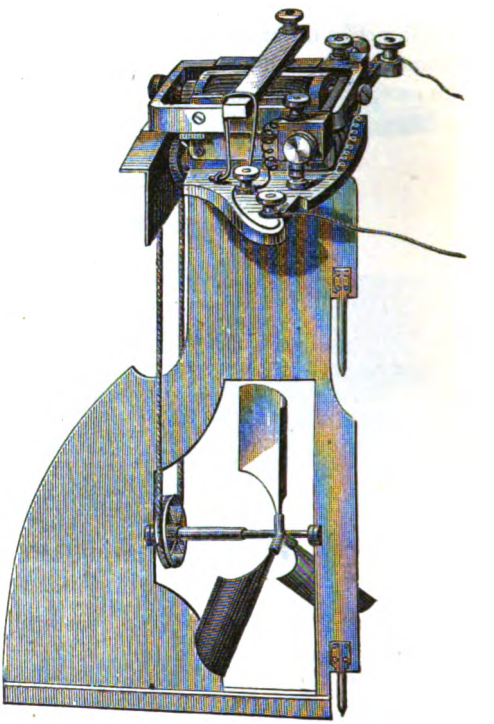


Fig. 630.—Trouvé's Propeller.

centimetres, and weighs 1,150 grammes. A chromate of potassium battery of six elements is used. To make the motor go faster or slower, the plates are dipped into the fluid deeper, or are lifted out by means of a lever, which has a treadle at the end, so that the person at the machine can regulate the speed with the foot.

All the machines we have yet considered have a Siemens armature; all their armatures, therefore, will have to undergo a change of polarity twice for every revolution. Now, as the rotation has to be very rapid, the change of poles has to take place in rapid succession; and in this feature lies the chief defect of this kind of machine. The soft iron, as we have seen in preceding pages, requires a certain time for altering its magnetic condition; therefore, during the

rapid rotation of the armature, the iron will still possess one kind of polarity, when the current in the surrounding coils has already changed its direction,

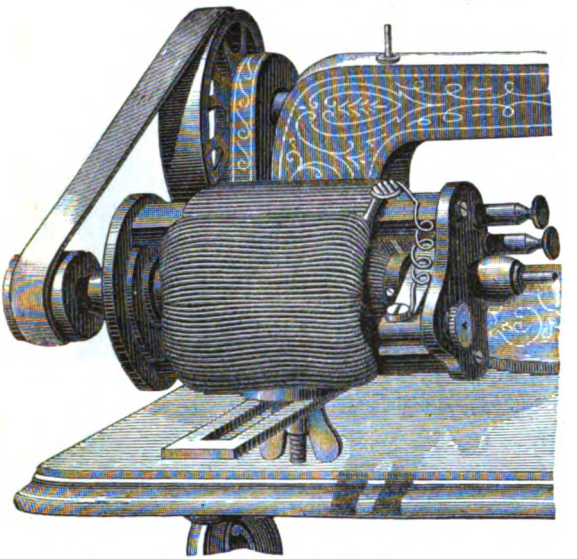


Fig. 631.—Griscom's Motor.

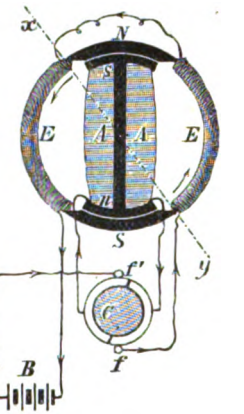


Fig. 632.—Section.

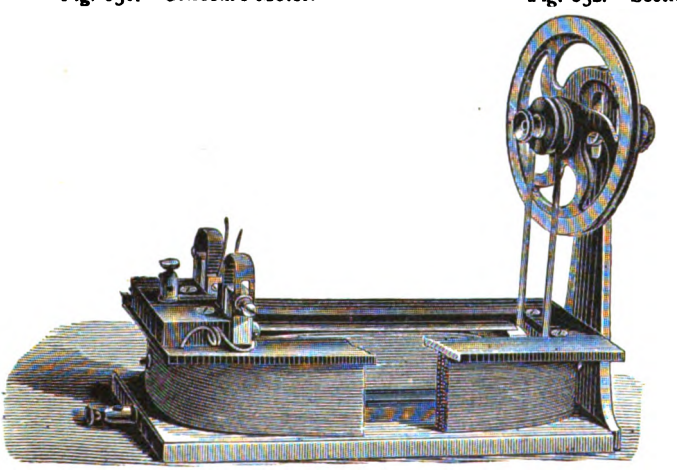


Fig. 633.—Borel's Motor.

and is trying to polarise the iron in the opposite direction. The result is that a portion of the current will be used for destroying the previous polarity, and only the remainder will be available for polarising the iron. The motors by Bürgin, Borel, and Jablochkoff are free from these drawbacks, as no change

of pole in the iron takes place in them. The first two are, in principle, massively constructed galvanometers, and behave in the same manner as these instruments. If a needle be hung within a coil, through which a current is passing, the needle will turn until it stands across the direction of the coil.

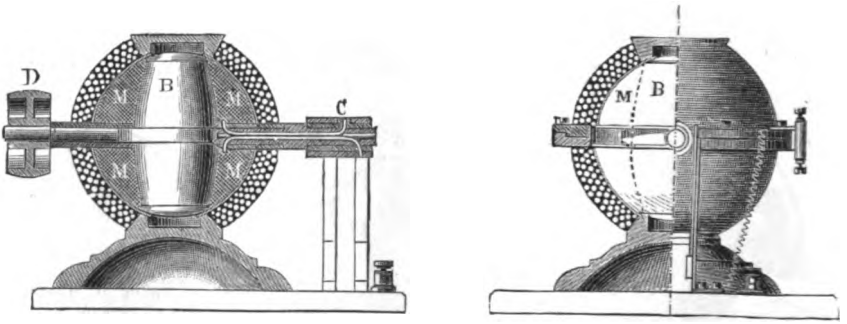


Fig. 634.—Bürgin's Motor.

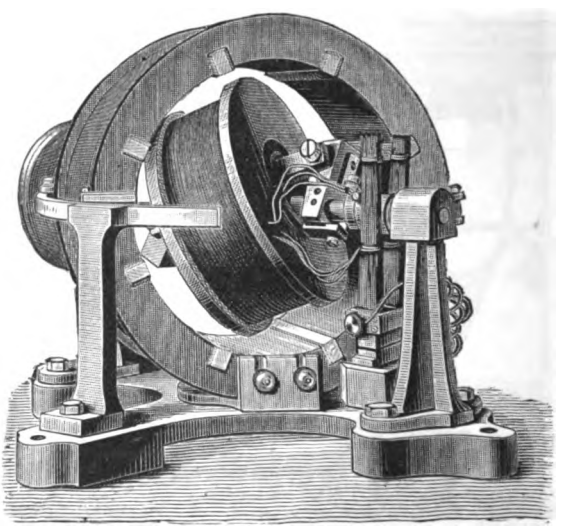


Fig. 635.—Jablochkoff's Ecliptic Motor.

The north pole of the needle will move towards that side of the coil on which the electric current flows in the same direction as the hands of a watch. If now, when the needle has this position, the current be changed in direction, the needle will turn through 180°, so that the north pole of the needle and the south pole of the coil will again face each other. In Fig. 633 it is shown how this principle has been utilised by Borel for the construction of an electro-motor. The needle here is replaced by an iron core, which turns in

a coil, and by means of a commutator this causes a continued oscillation of the current in the coil.

The motor by Bürgin, which is constructed on the same principle, is shown in Fig. 634. The iron core B, fastened upon a horizontal axis, has wire M M coiled round it, so as to appear spherically shaped at its outer surface. A spherical case, round which also wire is wound, covers the iron core and its wire coil. The commutator, which is fastened to the axis of rotation of the electro-magnet M B M, causes at every half-revolution of the electro-magnet a change in the direction of current in the outer turns of wire, bringing about in this manner a continued rotation. The motion is very rapid, as there is in the whole machine no change of magnetism that might oppose the rotation.

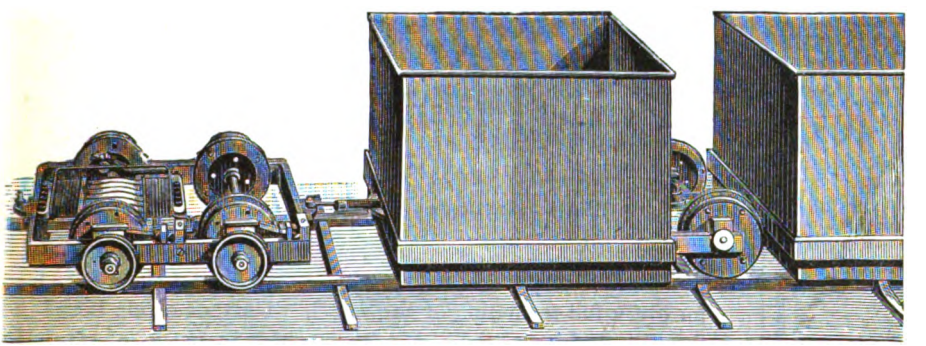


Fig. 636.—The Electric Letter-Post.

The motor *l'écliptique*, by Jablochkoff, is shown in Fig. 635. It consists of a fixed coil arranged vertically, and another coil which moves about a horizontal axis. The angle of inclination of the movable coil is determined by experiment, and depends partly upon the purpose for which the machine is intended. This coil is wound upon a core of soft iron, having circular discs of the same material on the sides. These discs form the poles of a short magnet when a current flows through the coil. The fixed coil contains no iron, but is wound upon a copper frame. The current is conveyed by means of a commutator, which forms part of the axis of rotation of the movable coil, and two brushes, so that the direction of the current in the movable coil remains constant, whilst in the fixed coil it changes at every half-revolution. Jablochkoff's motor may also be used as a generator of electricity.

A Parcels Railway.—It has been proposed to use small electric railways for the conveying of letters in large towns; they would take the place of the pneumatic letter-post, and would be considerably less expensive than the latter. The pneumatic post in Paris, for instance, requires 120 horse-power, while it is thought that 12 horse-power would be sufficient for an electric installation. A letter-post, as devised by Siemens, is shown in Fig. 636. The electro-

locomotive is a frame on wheels, which carries a very small Siemens machine of ordinary construction. The current from the generator passes along one rail to the wheel of this locomotive, then through the motor, and back by the other rail.

Edison's Electric Pen.—The smallest electro-motors are those used for the electric pen by Edison, in Fig. 637. The pen is used to perforate a sheet of paper, which can be used as a stencil-sheet to print from. The machine is 4 centimetres high and 2 centimetres wide. The electro-magnet E E is fixed to the frame A A; R is a little fly-wheel, the ends of whose axis rest in *b* and *d*. R, which rotates immediately before the poles of the electro-magnet E, has a bar magnet *n s*, arranged as shown in the figure. Upon the axis *b d*, the commutator *c* is fastened in such a way that the direction of currents sent through the coils of the electro-magnet changes twice for every full revolution of the wheel. The connection between the coils and battery wires is brought about by means of clamps, at *p* and *p'*. One of these clamps is connected with the commutator by means of the spring *f*, and its position can be regulated by the screw *t*. The shaft *b d* has a treadle-shaped crank, which actuates the end of the rod *s s*, causing an up-and-down movement of the rod when rotating. The needle N is fastened to the end of the rod, and passes through a tube F, which forms the pen-holder, and can be screwed to the frame at *x y*. When a current passes through the coils of the electro-magnet, the latter attracts the bar magnet, causing the wheel to turn in a certain direction. When, in consequence of this motion, dissimilar poles stand opposite each other, the commutator interrupts the current in the electro-magnet, and the wheel continues its motion; the commutator again makes contact; and the currents flow now round the electro-magnet in the opposite direction, and the polarity will be changed, so that now similar poles—for instance, *n* of the bar magnet and N of the electro—are near each other. Repulsion will take place now, and will urge the wheel to continue its rotation. The wheel makes sixty-five revolutions per second, during which it lifts the needle up and down about 130 times. When used the pen ought to be held vertical. From the drawing or writing thus produced 4,000 or 5,000 copies may be taken by placing paper under the stencil-sheet, and going over it with

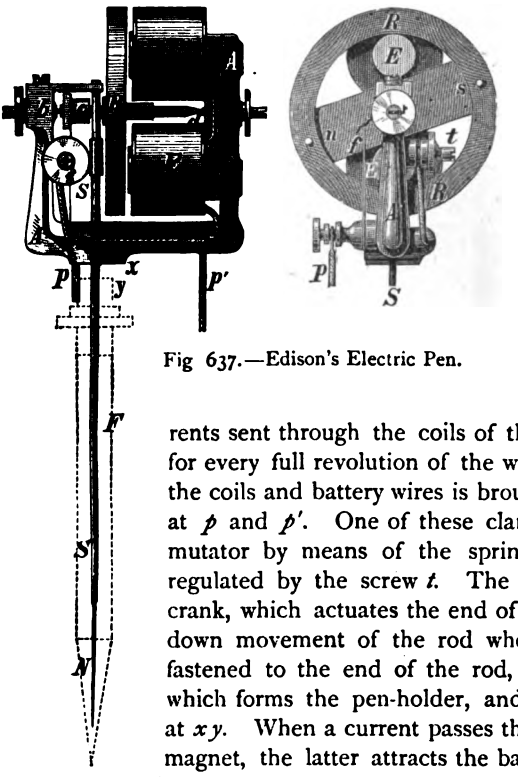


Fig 637.—Edison's Electric Pen.

an ink roller. A small two-element potassium chromate battery supplies the current.

The Phonic Wheel.—*The Phonic Wheel*, by Paul La Cour (Fig. 638), is distinguished for its steady and uniform motion. A toothed wheel of soft iron rotates past one of the poles of a straight electro-magnet, so placed that

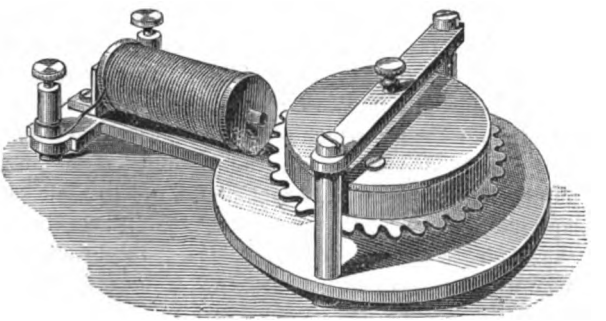


Fig. 638.—The Phonic Wheel.

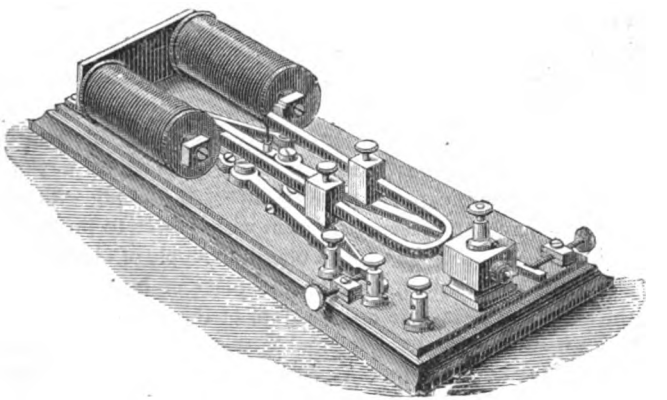


Fig. 639.—La Cour's Tuning-Fork Apparatus.

the teeth do not touch the magnet-pole. If a series of currents be allowed to pass at regular intervals through the coils of the electro-magnet, the wheel will receive a series of impulses which bring about a rotation of great regularity. The rate of motion of this wheel depends upon the number of current impulses given to it, and the width and number of teeth in the wheel itself. La Cour causes the continued impulses, or rather the vibrating current, by means of a tuning-fork. The tuning-fork for this purpose is placed horizontally between the poles of a horse-shoe electro-magnet in Fig. 639. Platinum contacts are fastened between the arms, so as to close the circuit of a battery when the

fork is at rest. The electro-magnet which is in the same circuit will now be induced, attracting the arms of the fork; at the moment when the arms begin to move outwards contact is broken, and the magnetic attraction ceases, so that the arms swing back into their original position and close the circuit again. It is clear that a continued breaking and making of current alternately takes place, and that the fork consequently vibrates. The tuning-fork can give only the one sound—that is to say, it can vibrate only at the same rate. It follows, therefore, that the current flowing through the circuit will always pass with the same regularity and velocity. La Cour calls such a current a phono-electric current. To increase the uniformity of rotation, the wheel has a wooden box fastened to it containing mercury, which serves the purpose of a fly-wheel.

As the velocity only depends upon the phono-electric current and the breadth and number of teeth in the wheel, it follows that all such wheels of the same size and number of teeth must rotate with the same velocity when one and the same phono-electric current passes. By means of the phonic wheel synchronism may be obtained between two or more pieces of apparatus, such as clocks.

Comparison of Heat and Electricity.—We will conclude this section with a brief examination of the difference between heat and electricity as regards their modes of mechanical action and availability for producing motive-power. Heat acts by expansion of volume (which is necessarily a wasteful principle), while electricity operates by attraction and repulsion—a mode that is subject to no greater loss of effect than attends the action of gravity in a hydraulic machine. If, then, we could only produce electricity with the same facility and economy as heat, the gain would be enormous; but, at present, the cheapest way of generating electricity is by the dynamic process. Instead of beginning with electricity to produce power, we have at present to begin with power to produce electricity. We know of no source from which we can obtain a supply of electricity sufficiently cheap and abundant to enable it to take the place of heat as a motive-energy. We obtain the supply of heat from combustion, or the consumption of fuel in its union with oxygen, and we probably cannot expect to find other bodies capable of yielding energy by a cheaper process. We cannot get energy of affinity where affinity has been already satisfied, and the bodies composing the mass of our globe are in combination already. We might as well try to make fires of ashes, as to use such bodies over again as sources of either heat or electricity. The only abundant substances in nature possessing strong unsatisfied affinities are organic bodies and coal. Until some means be found of making the combustion of coal available for producing electricity directly, we cannot hope to obtain electricity at such a cost as to supplant heat as a motive-agent. It is, therefore, as secondary motors (for the transmission of power), and not as primary motors, that we may expect electric engines to play a more important part in the future.

THE TELEPHONE.

Reis's Telephone.—It was discovered by Page, in 1837, that an iron bar, when magnetised and demagnetised at short intervals, emits sounds; and on the basis of this experiment Philip Reis constructed his first telephone. Philip Reis was born on the 7th of January, 1834; he received a good elementary education, and entered a business-house when 16 years of age, but for some years

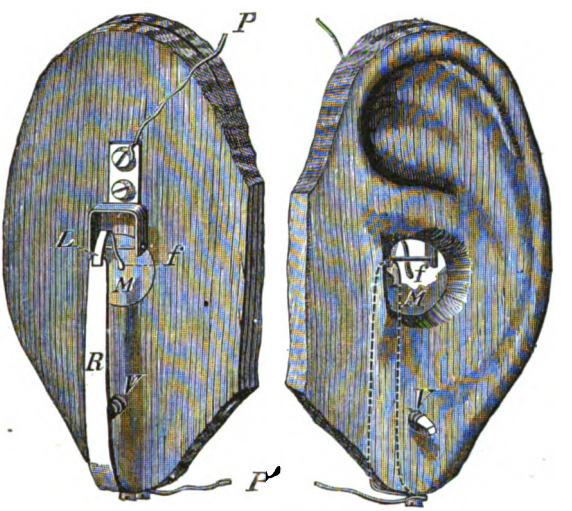


Fig. 640.—Reis's Telephone.

devoted his leisure time to the study of mathematics, chemistry, and physics, attending lectures delivered at the commercial institute. He left business, however, and entered Dr. Poppe's establishment at Frankfurt, to qualify himself for a teacher. The first apparatus made by Reis, according to Dr. Messel, consisted of a beer-barrel, in the bung-hole of which a small cone was placed, covered at its smaller end with an animal membrane, upon which a small platinum strip or wire was fastened by means of sealing-wax. The receiver consisted of a violin, upon which a knitting-needle, having a coil wound round it, was fastened. The receiver was afterwards made in the form of the human ear (Fig. 640). Here the platinum wire *f* was fastened to the membrane M, and to the spring R, by means of sealing-wax, and a platinum contact L was placed opposite *f*. A screw V adjusted the spring. The wires P P′ connected the apparatus with the battery. When sound-waves made the membrane M vibrate, the circuit P *f* L R and P′ was made when *f* and L touched each other, and broken when they parted. The last modification of the apparatus is shown in Fig. 641. It consists of three

parts, A (the sender), B (the battery), C (the receiver). These three portions are connected with each other by means of wires. The upper portion of A is shown separately at D. *m m* is the tympanum of stretched membrane, having attached to it *n s*, the platinum strip. When the membrane vibrates, in response to the impulses of sound, this elastic strip of platinum beats to and fro against a tip of metal, altering the degree of contact at each vibration. The angular

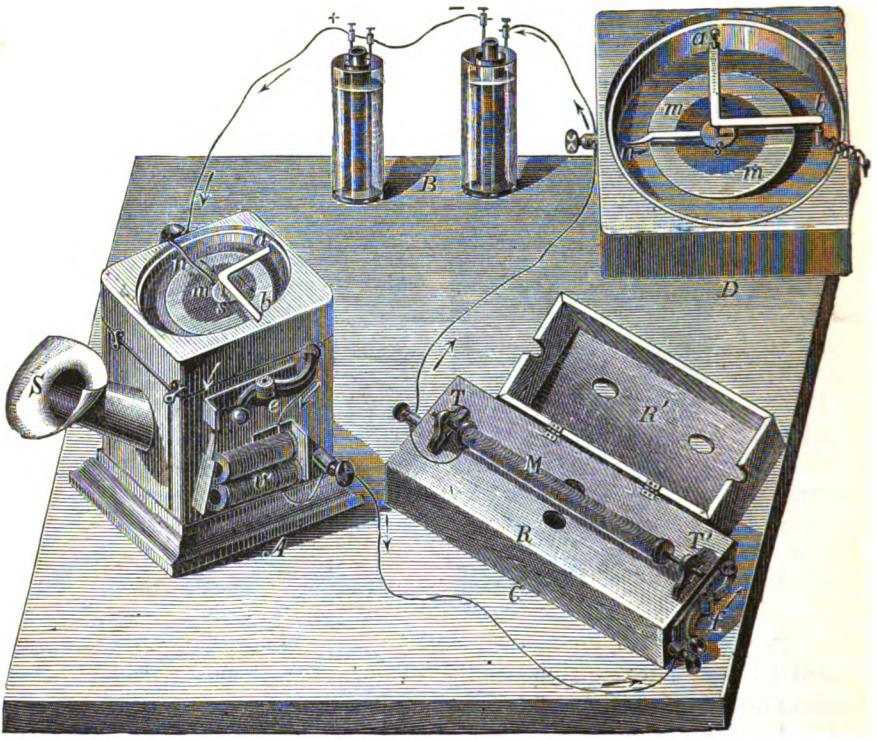


Fig. 641.—Reis's Telephone.

piece *a b*, which carries the contact-tip, is made of brass, and dips at *b* into the mercury-cup, to which the battery wire is brought; the receiver C consists of an iron needle, 21·5 centimetres long and 0·9 millimetre thick, round which the coil M is wound. The rapid magnetisation and demagnetisation of this iron wire produced sounds having the same frequency, and therefore the same pitch, as the note sung into the transmitter. Reis showed his apparatus for the first time to the Physical Society of Frankfurt in 1861. Much has been said and written as to whether Reis's telephone was capable of transmitting words, or sounds only. That it transmitted words is proved by the following letter, which Reis wrote to F. J. Pisko:—

Hochgeehrter Herr!

In Erwiederung Ihres Geehrten vom 16 d. Mts. sage ich Ihnen zunächst m. Dank für Ihre freundliche Theilnahme für m. Erfindung & für die gütige Zusendung Ihrer interessanten Schrift.

Ihrem Wunsche, die Zusendung von Abhandlung & Zeichnungen betreffend kann ich nur sehr unvollkommen entsprechen, da es mir m. Zeit nicht erlaubt alle die Anforderungen zu berücksichtigen, welche von den verschiedensten Seiten in diese Beziehung an mich gestellt werden.

Ich verweise Sie deshalb auf die einzige von mir veröffentlichte Abhandlung (Bericht des physikalischen Vereins zu Frankfurt a/M), 1860–1861, dessen Sie jedenfalls dorten habhaft werden können. Ferner wird der Apparat neuster Construction beschrieben in Pouillet-Müller's Lehrbuch der Physik neueste Auflage (unter der Presse). Noch füge ich die Erklärung bei, wie sie jedem Apparat beigefügt wird & sage Ihnen, daß Herr Mech. Hauk dorten bereits einen Apparat bezogen & Ihnen jedenfalls Auskunft geben kann.

Was Ihre Auseinandersetzungen auf Seite 15 Ihres Programms betrifft, so sind die gemachten Schlüsse, obgleich vollständig auf früheren Thesen fußend, total falsch (eben weil jene Thesen falsch sind.) Der Apparat gibt ganze Melodien, die Tonleiter zwischen C & $\bar{\bar{C}}$ ganz gut & ich versichere Sie, daß wenn Sie mich hier besuchen wollen, ich Ihnen zeigen will, daß man im Stande ist allerdings auch Worte zu verstehen.

Wie machte denn das Trommelfell in unserem Ohr um alle Töne mit ihrer Klangfarbe, Accorde etc zu reproduziren???

Am besten wird es immerhin sein wenn Sie sich selbst von der Einfachheit & Richtigkeit der Thatsachen überzeugen.

Mit besonderer Hochachtung

Ihr Ergebenster

Friedrichsdorf 18/10 63.

Ph. Reis

From this letter we translate the following extract :—"The apparatus gives whole melodies in any part of the scale between C and c''' well, and I assure you, if you will come and see me here, I will show you that words also can be made out." Reis was well aware of the importance of his invention, which, at that time, was treated as a toy. He remarked to Garnier "that he had shown to the world a road to a great discovery, but left it to others to follow it up." Reis died in 1874. Although the priority of the German inventor, Philip Reis, cannot be disputed, Reis's telephone had to undergo many modifications before it could be utilised for practical purposes. S. Yeates (1865), Wright (1865), C. Varley (1877), C. and L. Wray (1876), E. Gray (1874), Van Der Weyde,

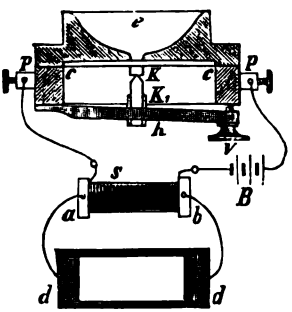


Fig. 642.—Pollard and Garnier's Singing Condenser.

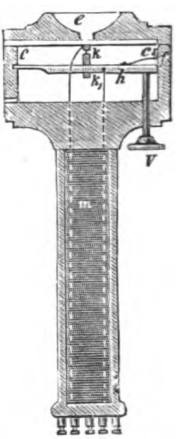


Fig. 643.—Janssens' Telephonic Apparatus.

and Pollard and Garnier, all tried to bring the telephone to a state of greater perfection. The singing condenser, simplified by Pollard and Garnier, is shown in Fig. 642; *d d* is the condenser, consisting of tin foil placed between pieces of paper. The transmitter consists of a wooden ring, which is closed by means of the thin iron plate, *c c*, over which the mouth-piece *e* is arranged; K, the contact-piece, consists of retort coke, and is fastened immediately opposite the narrow opening of the mouth-piece, *i.e.* in the centre of plate *c c*. K_1, of the same material, can be adjusted by means of the screw V and wooden bar *h*. When the iron plate *c c* is at rest, K K_1 do not touch each other, but they will make contact on the slightest vibration of the plate, allowing the current of the battery B to pass. This battery consists of six Leclanché elements. One of the clamps *p* is connected with K, and the other *p'* with K_1. One pole of the battery is connected with one of these clamps *p'*, the other with the primary coil of the induction spiral S. From the copper fastenings of the condenser the wires lead to the secondary coil. When the plate *c c* is made to vibrate by singing into the mouth-piece *e*, vibrating currents are sent through the primary spiral,

causing similar induced currents in the secondary spiral. The condenser then begins to sound, imitating the singer more or less closely.

Janssens' Modification of Reis's Telephone.—A further simplification of the apparatus, given by Janssens, is shown in Fig. 643. The transmitter is enclosed in a wooden box, ending in a tube, which has the induction spiral *m*; *c c* is the iron plate; K and K_1 the two carbon pieces, and *w* is the lever carrying the lower carbon piece; *v* is the screw, *f* a spring for adjustment. In order to allow the air enclosed in the box to vibrate freely, holes are cut in its side.

Bell's Telephone.—We shall now consider the magneto-electric telephone, as constructed by Graham Bell. Mr. Bell came to Boston in 1868, as a teacher of the deaf and dumb. The deaf and dumb are not, as a rule, unable to speak because their organs of speech are defective, but because, in consequence of their deafness, they cannot hear the spoken word, and therefore cannot imitate

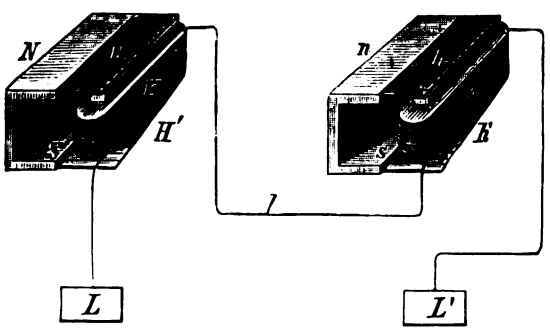


Fig. 644.—Bell's Electric Harmonica.

it; it is, therefore, usual to teach them to speak through other agents than the ear. For the further development of this method, Graham Bell and his father, Alexander Melville Bell, studied the mechanism of the voice. Graham Bell produced vowels artificially by means of tuning-forks, and, aided by Helmholtz's investigations (1859—1862), he made use of the electric current for his experiments. The first form of Bell's telephone is shown in Fig. 644. A stave harmonica H H′ is fastened to the poles of the permanent magnet N S, and between H and H^1 a coil of wire, surrounding a soft iron core, is placed. An exactly similar instrument is formed of a second permanent magnet *n s*, and the ends of the two coils E and *e* are connected either by two lines or by one line wire *l* and the earth L L′. When any one of the staves H is made to vibrate—that is to say, to approach or recede from the core E—it will strengthen and then weaken the induced magnetism of E, and, as a consequence, currents will be induced in the coils of the electro-magnet E. The currents will flow through the coil of the second electro-magnet *e*, connected by means of the wire *l* and the earth-plates L L′ with the first. Therefore one of the staves *h* upon the permanent magnet *n s* will be attracted and repelled, *i.e.* will also begin to

vibrate; but the impulses which the electro-magnet *e* receives are exactly the same as those induced in E through the vibrating of the stave; consequently *h* will have the same vibration. Further, each stave can only produce that vibration peculiar to it, and of the staves in *h* only the one will continue to vibrate whose natural rate of vibration synchronises with the impulses corresponding to the stave in H. If each prong of H be struck in succession, the prongs in *h* which are in unison with those of H will sound in succession; and if a tune be played on the prongs of H, the same tune will be heard from *h*.

The expense of such an apparatus prevented Bell from developing and perfecting this idea. He, however, investigated the different kinds of vibration obtained through different effects of current, and was led to distinguish between

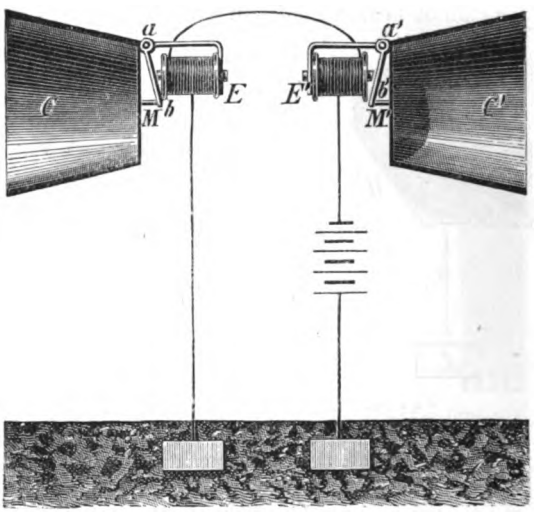


Fig. 645.—Bell's Second Telephone.

three different kinds of currents. Let us assume that the body which is to be made to vibrate is an iron plate, and the body causing the vibration an electro-magnet. If the latter be magnetised and demagnetised by the making and breaking of the current in quick succession, Bell calls this current an intermittent one. If care be taken that a distinct, although weak, current flows through the circuit, which is weakened and strengthened by the approach and recession of a magnet, then this current is called by Bell a pulsating current. These two kinds of current were made use of in the older telephones. Plates set in vibration by these methods trace out undulations which, when represented graphically in the indicator diagram, show angular lines corresponding to the sudden make or break of current. But the human voice consists of continued sounds and noises, and it is therefore evident that neither by means of the pulsating nor of

the intermittent currents will words be thoroughly reproduced. Speech can only be reproduced when exactly the same vibrations can be obtained at the place where the reproduction has to take place. For this purpose Bell uses currents which he calls undulating currents, the characteristic of which is that they increase and diminish, not abruptly, but gradually. Indicator diagrams obtained with these currents show wave-shaped lines, which rise and fall gradually. Undulating currents are, therefore, capable of copying the human voice, as they can excite short and quick, as well as long and slow waves.

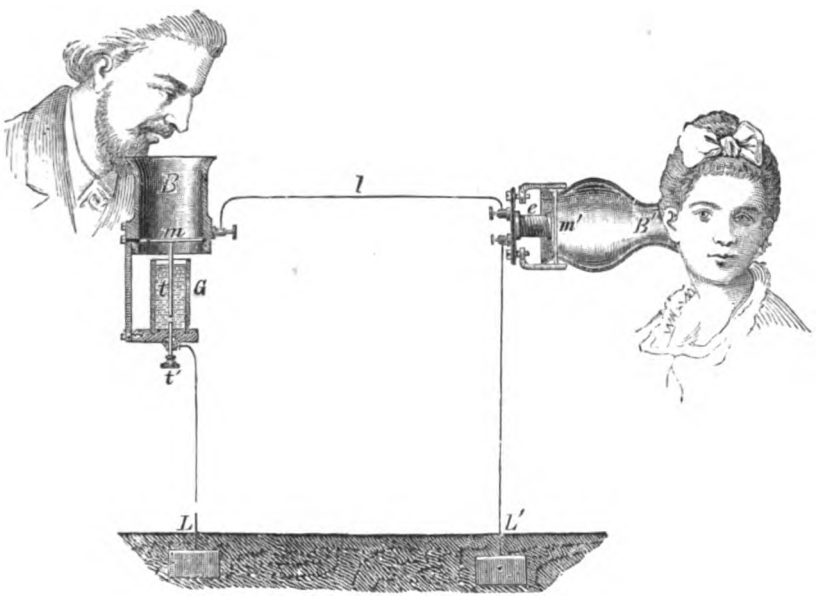


Fig. 646.—Gray's Telephone.

Bell's Second Telephone.—The next apparatus that Bell constructed is shown in Fig. 645. The cone C had its smaller opening closed by means of a gold-leaf M, which was connected by means of a little rod with the armature *a b* of the electro-magnet E. The cone C′, exactly similar to the first, was fitted in a similar manner with membrane M′ and electro-magnet E′. When the membrane M, excited by sound-waves, began to vibrate, the armature, which vibrated along with it, induced undulating currents in E, which caused the same vibrations on the membrane M′ by means of the magnet E′, and its armature *a′ b′*. Bell took out a patent for this form of apparatus on the 14th of January, 1876.

Gray's Telephone.—About the same time Elisha Gray's agent also requested a patent for a telephone. In Gray's telephone, shown in Fig. 646, the sender and receiver are differently shaped. The membrane of the sender B

has at its lower side the metal rod *t*, the continuation of which is formed by the screw *t'*. The rod *t* passes through a vessel G, which is filled with a bad-conducting fluid. The receiver consists of the vessel B', which is closed at one side by the membrane *m'*. The membrane has a piece of soft iron attached to it in the middle, and opposite to this is placed the electro-magnet *e*. The two parts of the apparatus are connected with each other by means of the wire *l* and the earth-plates L L', and are inserted into the circuit of a battery. The membrane which is made to vibrate by speaking, inserts by means of the rod *t* more or less resistance in the circuit, producing, if we may use Bell's expression, pulsating currents, which are conveyed to the electro-magnet of the receiver, and cause the membrane *m'* to vibrate like the membrane *m*.

Bell and Gray disputed about this latter patent, and the dispute was decided in favour of Bell.

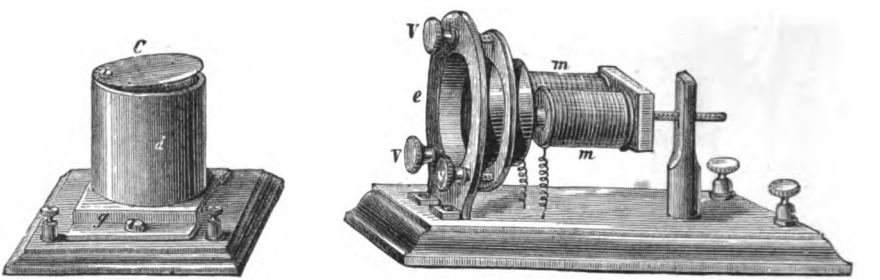


Fig. 647.—Bell's Third Telephone.

Bell's Third Telephone.—The results which Bell obtained with the apparatus represented in Fig. 645 did not satisfy him, and his next step was to give the sender and receiver the forms shown in Fig. 647. The former consists of the electro-magnet *m m*, placed behind a metal ring *e*, the screws of which v v serve to hold a parchment membrane in position before the magnet-poles. To the membrane is glued a plate of soft iron serving as armature for the electro-magnet. The receiver consists of a straight electro-magnet, which is surrounded by an iron tube *d*, the iron plate *c* of which serves as armature. This plate c is fixed on one side only; *g* is a resonance bridge placed between the ground frame and apparatus. When anything is spoken against the membrane of the sender, it vibrates with its iron plate, and generates undulation currents in the electro-magnet *m m*; these flow through the wires to the receiver, making the iron plate c vibrate in the same manner as the membrane of the sender.

The Bell telephone was exhibited at Philadelphia in 1876 in this form (Fig. 647). Although satisfactory results were obtained with the instrument, it had the drawback that its receiver could only be used as a receiver, and not at the same time as a sender. Bell then constructed the apparatus which we shall describe after we have discussed another instrument now very commonly used as the "sender" in a telephonic circuit. The Bell telephone, in its final

form, is capable of transmitting speech perfectly and exactly, provided the distance between the two stations be not too great.

The Microphone.—Before the telephone could be brought to the commercial importance, however, that it has at present, there was still a problem left to be solved, the solution of which was effected by the discovery of the microphone. Hughes, the inventor who first applied the name, gives as the essential feature of the microphone, the presence of a conductor capable of changing its resistance with the sounding vibrations. The scientific principle, according to which the resistance is made to vary by the vibrating body, was discovered by Th. du Moncel in 1856. It may be stated as follows :—When an electric current passes through the point of contact of two bodies, the electric conductivity changes with the change of contact pressure of the two bodies. Carbon, which is especially adapted for contacts of varying resistance, was first practically made use of for telephony by Edison, in his carbon telephone, the description of which will be given later on.

Berliner's Microphone.—Fig. 648 represents a microphone for which E. Berliner, in Boston, took out a patent on the 7th of July, 1877. The

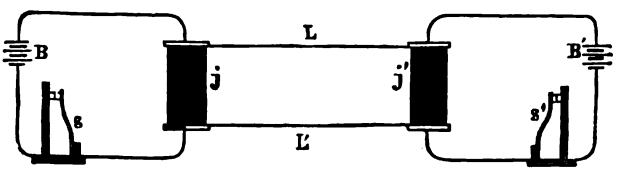


Fig. 648.—Berliner's Transmitter.

apparatus at the receiving and sending stations is similar in construction, and each consists of a battery, an induction coil, and carbon contacts, to form a microphone. The secondary spirals of the induction coils J J′ are constructed by the wires L L′. The primary coils are inserted in the circuits containing the batteries B B′, and the carbon contacts S S′.

Dr. R. Lüdtge obtained a German patent on the 12th of January, 1878, for his "universal" telephone; but it would lead us too far to record here all the microphones that have been patented. Professor Hughes was the first who treated microphonic phenomena systematically, and is, therefore, considered to be the inventor of the microphone. His investigations were made known to the Royal Society of London in 1878.

Hughes' Experiments.—We shall here find it convenient to describe some of the experiments made by Hughes in the process of perfecting and studying his invention under varying conditions. A glass tube of about 8 centimetres in length was filled with bronze powder, and the ends were closed by means of retort coke, so that the metal powder was gently pressed together. The wires fastened to the carbon plugs formed a closed circuit with a battery and a galvanometer. When a pressure or pull with both hands was exerted on the tube,

the galvanometer needle showed a powerful deflection. The tube proved also convenient for producing a simple telephonic apparatus. For this purpose the tube was placed upon a resonance box (Fig. 649), the plug *y* was connected with a battery B, and the plug *x* with a Bell telephone T. Words spoken into the resonance box could be heard distinctly in the telephone T placed at various distances. The same results were obtained when, instead of the glass tube, a rod of charcoal was taken, which had been previously brought to white heat, and then dipped in mercury. A still simpler arrangement tried by Hughes is that shown in Fig. 650. It consists of two wire pins, placed parallel to each other, and a third one simply laid across them; the pins X and *y* are joined in the circuit. In this arrangement the contacts of the cross-pin with the pins underneath form the changeable resistance which brings about the microphonic effects.

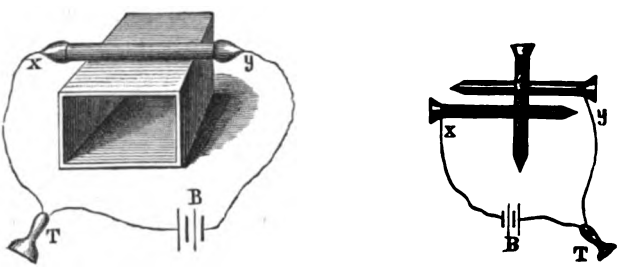


Fig. 649.—Hughes' Microphones without Carbon.—Fig. 650.

Microphones of greater sensibility are shown in Figs. 651 and 652. Upon the platform D, Fig. 651, a resonance board is fastened vertically, and made to carry two carbon blocks C C, between which the carbon rod A is placed. The wires *x y* are fastened to the carbons C C. To experiment with this microphone, it is placed upon cotton-wool, or upon two pieces of india-rubber tubing. The wires *x y* are connected with a Bell telephone, and a battery consisting of one to two Leclanché or three Daniell elements. The vibrations of sound, when conveyed to the points of contact of C C and A, either directly, by the air, or through the board, alter the resistances at these points, and so strengthen and weaken the current alternately for every pulse. The changes of current will affect the magnet of the distant telephone, and reproduce the vibrations in the telephonic plate. The instrument is so sensitive that a fly walking across D can be heard through the telephone. Words spoken even at a distance of from 8 to 10 metres from the microphone are distinctly heard. As the efficiency of a microphone is greatly dependent upon the kind of contact, it is advantageous to make the latter so that it can be regulated. This may be easily brought about, in the manner shown in Fig. 652. To ascertain the most effective position of the two carbons with regard to each other, a pocket watch, for instance, is placed upon the sounding-box of the microphone; the ticking

is observed through the telephone, and the two carbons are regulated by means of the screws until the best effects are obtained.

So far we have had under consideration the historical development of telephony; we have now to consider the practical applications of these instruments.

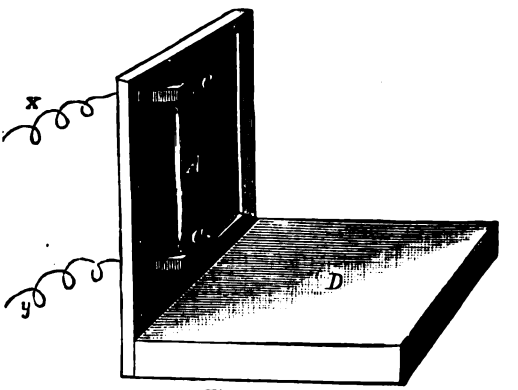


Fig. 651.

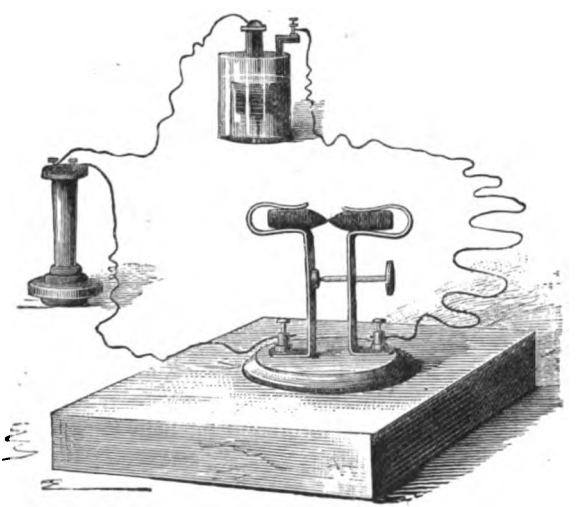


Fig. 652.—Hughes' Carbon Microphones.

BELL'S TELEPHONE AND ITS MODIFICATIONS.

Explanation of the Theory of the Telephone by Faraday's Lines of Force and Maxwell's Rule.—When a closed conductor is moved across the lines of force in a magnetic field, a current of electricity is generated whose strength depends upon the velocity of motion of the conductor

and upon the intensity of the magnetic field. Conversely, when lines of force are projected through a closed conductor, a current of electricity is generated in that conductor, whose strength depends upon the magnetic intensity of those lines of force. In other words, when a closed circuit moves in a magnetic field so that the number of lines of force passing through the circuit is altered, then a current is produced in the circuit; and, conversely, when the closed circuit is stationary, but the field either moves or alters its form so that the number of lines of force projected through the circuit alters, then also a current is generated in the coil. The direction of the current is given by Lenz's law, viz. that the current produced tends to resist the motion producing it. The latter or converse form of the rule is the principle of the telephone, which proves that the form and duration of the current is dependent upon the rate and duration of the motion of the lines of force.

Let N S (Fig. 653) be a permanent magnet, and *a b* a fixed closed conducting ring of copper wire around one pole of the magnet. Let *c* be a movable iron armature. Now if we regard any two lines of force, F 1 F 1, radiating from the pole N, and nearly cutting the ring *a b*, then, as we make *c* approach or recede from N, those lines of magnetic force will change their direction, taking up position 2: and with each change of direction they will cut the ring *a b*, and currents of electricity in different directions will circulate through *a b* according to the direction of motion of the lines of force; and the rate of increase and decrease of magnetic intensity (or of the increment or decrement of the current) will vary directly with the rate of motion of the armature *c* to or from the pole N. Thus if *c* be a disc of iron vibrating under the influence of sound, the excursions to and fro of any point of the disc, though very small, are nevertheless sufficient to produce that motion of the lines of force which results in currents. It bends the lines of force cutting *a b*, and thereby produces undulating currents of electricity in the ring *a b*, whose number depends on the number of vibrations, and whose form and intensity depend on the rate and amplitude of motion of the disc *c*.

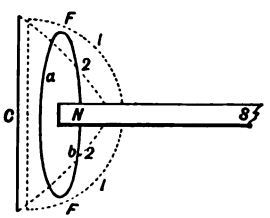


Fig. 653.—Theory of the Bell Telephone.

These currents are alternate, and so rapid that no known instruments but the telephone indicate them; but they are readily shown by a Thomson's reflecting galvanometer, when the disc is gently and slowly pressed in by the finger—in one direction when the disc is pressed in, and in the other when it is allowed to recover its first form. The vibrations of thin discs under the influence of sounds can be made optically visible in many ways. One method is to stretch an india-rubber membrane over the end of a speaking-tube, with a small mirror cemented in the centre: on singing into the tube a spot of light reflected from the mirror will describe on a screen the most extraordinary figures. But a more

perfect and beautiful method is to place across the end of the speaking-tube a plate pierced by a hole 30 to 40 millimetres in diameter, closed by a soap-film. On singing into the tube, all the vibrations can be seen in the film, producing the most intricate and complicated figures, which change with every note. Such an instrument is called a Phoneidoscope. Its figures may be readily projected upon a screen with the aid of a lantern, or may be seen with the naked eye in the film itself, and give a vivid idea of the complicated vibrations which take place in a thin plate under the influence of sound.

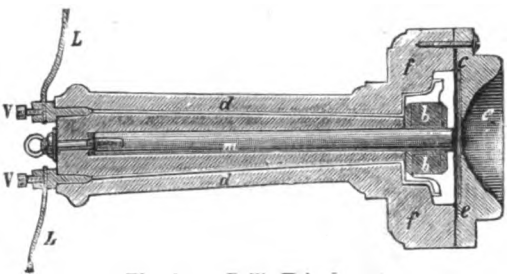


Fig. 654.—Bell's Telephone,

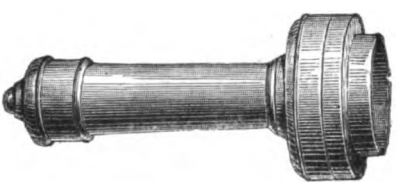


Fig. 655.—Bell's Telephone.

The ultimate form which Bell gave to his instrument is shown in Fig. 654. *m* is a powerful bar magnet, encased in a wooden frame *f f*, the end of which is surrounded by the induction coil *b b*. The ends of the coil are soldered to thick copper wires *d d*, which terminate in the clamps v v. The distance of *m* from the thin iron disc *c c* can be regulated by means of a screw. The sheet of iron has that side which can be seen from *e* coated with varnish or tin to prevent oxidisation. The strength and length of the wire for the induction coil must be proportional to the resistance which exists in the circuit of the telephone. The instrument acts best when the magnet is powerful, and the turns of the induction spiral are numerous, and when the iron disc is placed very near to the magnet. This distance has, however, to be arranged so that the disc, even in its most violent vibrations, does not come in contact with the magnet. For convenience in the handling of the instrument, the clamps v v are, as a rule, covered, as shown in Fig. 655. A mouthpiece *e* collects and concentrates the voice.

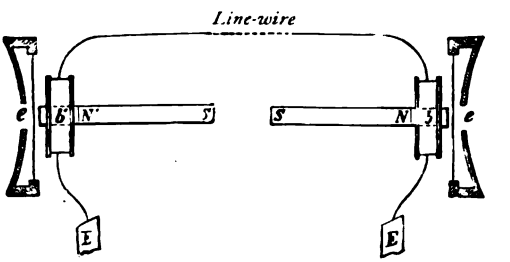


Fig. 656.—Diagram of Transmitter and Receiver.

Bell's telephone may be used both as a receiver and a transmitter. Fig. 656 represents two Bell telephones which are exactly alike, each of which may be used either as a receiver or as a transmitter. *b b'* represent the induction coils, N S and N' S' the magnets, and *e e* the speaking-funnels with the iron

discs. The ends of the coils are connected with the earth-plates E E on the one side, and with the line on the other.

It will now be understood that when the sheet-iron disc of a telephone is made to vibrate by speaking into it, the position of the sheet as regards the magnet will be continually changing; but the changes between magnet and

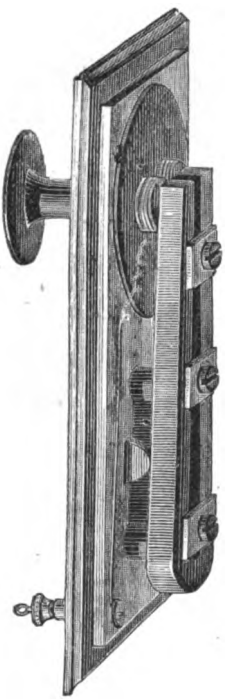


Fig. 657.—Bell's Telephone.

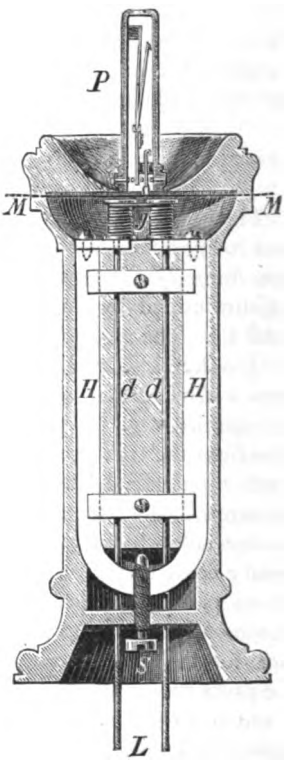


Fig. 658.—Siemens' Telephone.

sheet cause corresponding changes in the magnetism of the iron. The latter is surrounded by a coil *b*, which is connected with a similar coil *b'* in the same circuit. The current impulses produced in the coil *b* through the alteration of the magnetism of N S (or rather of the shape of the lines of force between N and the disc, whereby a larger or smaller number pass through *b*) will, therefore, be conveyed through the whole circuit, and will appear at the receiving station in the coil *b'*—hence, the iron sheet at the receiving station will vibrate, and exactly copy the sound-waves at the sending station. The nature of these vibrations is fully explained in the work of Th. du Moncel, *Le Télephon.*

The circuit offers a resistance to the current impulses, and so weakens them, and this is why the words sound indistinct, as if coming from a distance.

The object which the improvers of Bell's telephone have had in view is to reproduce words at a receiving station placed at a considerable distance from the telephone. Bell constructed telephones which were specially designed for this purpose, by using which it was possible to hear music, at all events, in all parts of a moderately large room. One of these arrangements is shown in

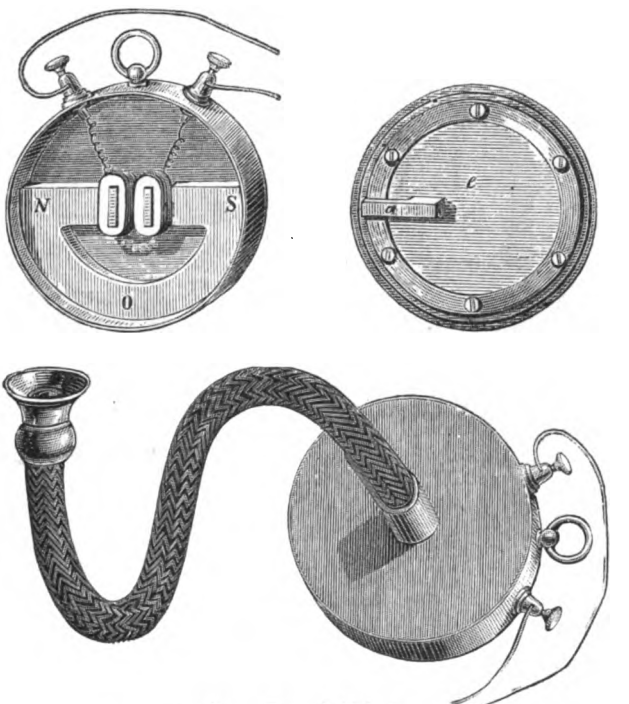


Fig. 659.—Gower's Telephone.

Fig. 657. In the lid of a box (left out in the figure) a circular hole is cut out, and is covered by the sheet-iron disc. The latter has a thickness of from 0·4 to 0·8 millimetre, and is fastened by means of screws to the lid. The speaking-funnel (the tube of which must not be very short) is arranged opposite the centre of the sheet. The poles of a powerful horse-shoe magnet are opposite the other side of the sheet. The poles are prolonged by iron pieces directed vertically towards the sheet, each of which is surrounded by an induction coil.

Many attempts have been made to increase the effects still more. Niaudet, for instance, uses four iron pieces, and arranges the four coils in a square.

Fig. 658 represents one of the modifications of Bell's telephone by Siemens. Here again the poles of a horse-shoe magnet are placed opposite the disc, so as to produce a more powerful effect than that of the single pole of a bar magnet. H H represents the horse-shoe magnet, J are the two induction spirals, and opposite these is the iron disc M M. The ends of the induction coils are connected with the copper wires *d d*, ending in the leads L. The position of the magnet may be so regulated, by means of the screw S, that its poles are in the most advantageous position as regards the iron disc. P is a whistle which is placed in the lower opening of the speaking tube, and may be used as a signal.

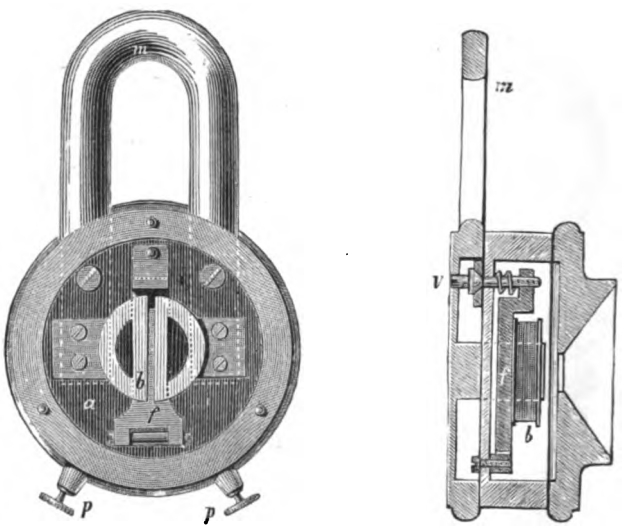


Fig. 660.—Fein's Telephone.

Gower's Telephone, which was at first thought highly of because of its extraordinarily powerful effects, is shown in Fig. 659. The horse-shoe magnet N O S is bent into a semi-circle, and the ends of its arms are bent at right angles to the plane of the magnet. The bent portions carry the oval-shaped induction coils. The magnet formed in this manner is very powerful, and, according to Th. du Moncel, capable of carrying a weight of 5 kilogrammes. The ends of the induction coils are connected with clamps that are fastened to the outside of the metal box enclosing the apparatus. The sheet of iron *e* is larger and made of stronger material than is generally used for telephones. The signalling apparatus consists of the tube *a* bent towards the iron sheet, inside which a small vibrating tongue is placed: this can be agitated by blowing into the flexible tube, through the mouthpiece fastened to the back of the case.

The telephone by W. Fein, of Stuttgart, shown in Fig. 660, is similar to

the apparatus just described. The horse-shoe magnet *m* is so arranged that only the poles are inside the telephone case. The iron cores are arranged at right angles to the plane of the magnet, and in order to make them more sensitive to the effects of the currents, they are made of thin plates or wires. The cores as well as the coils *b* surrounding them have semi-circular sections, so that their effects upon the iron sheet may be more regular. By adopting this form, both coils when put together have the same circular plane cross-section. The ends of the induction coils are connected with the clamps *p p*. The brass lever *f*, which can be made to affect the iron cores by turning the screw v, serves to adjust the telephone.

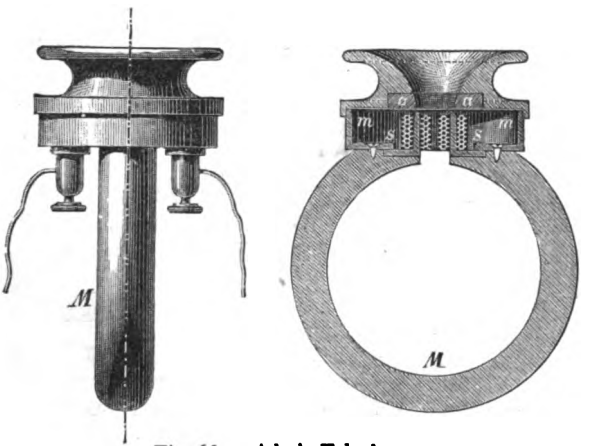


Fig. 661.—Ader's Telephone.

Ader's Telephone.—Cl. Ader constructed an effective telephone by making use of the principle that an iron plate inserted between a magnetic pole and its armature is affected inductively as if it formed part of the armature. We know that when a piece of iron is brought near a magnet it becomes magnetised by induction. That side of the armature which is nearest the north pole of the magnet receives south magnetism. If we now bring a thin iron plate between the magnet-pole and the armature, we find that the distribution of poles in the armature has not altered, and the lines of force pass right through the thin plate. According to the law of induction, that side of the plate facing the north pole of the magnet should show south magnetism, and so on. Experiments, however, such as the production of magnetic curves by iron filings, show that the thin iron plate between the north pole of the magnet and the south pole of the armature has exclusively south magnetism. This behaviour of iron plates may further be illustrated by the following experiment: A thin plate is brought before the poles of a powerful horse-shoe magnet, but at such a distance as hardly to be attracted by the magnet; if now an armature be placed before

the magnet so that the iron sheet is between the magnet and the armature, the iron plate will be immediately attracted by the magnet. The effect obtained by means of the armature may be explained by supposing both sides of the sheet to have the same kind of magnetism : Similar poles stand opposite each other on the side of the armature, and repel each other, but dissimilar poles towards the magnet attract each other. The attractive force of the latter is aided by the repulsive force of the former, and therefore the disc moves towards the magnet.

The apparatus shown in Fig. 661 is constructed on this principle. The circular-shaped horse-shoe magnet M has the induction coils S S surrounding its pole-projections, and opposite to these the iron sheet *m m* is placed. *a a* is a ring of soft iron, which is placed inside the mouthpiece of the telephone, so as to form the armature of the horse-shoe magnet. The thin sheet is placed between the

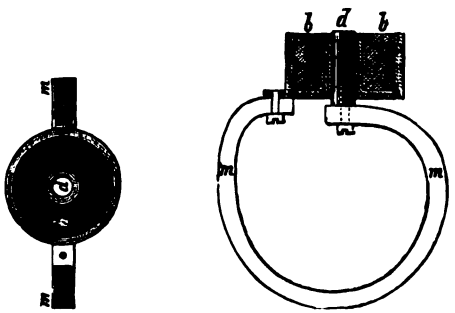


Fig. 662.—D'Arsonval's Telephone.

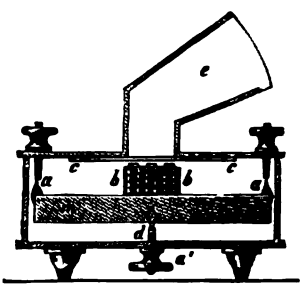


Fig. 663.—Böttcher's Telephone.

magnet-poles and the armature, and will therefore be exposed to strong magnetic influences. Ader rounds the magnet carefully off and then nickel-silver plates it, to give to the apparatus a neat appearance and a convenient form.

D'Arsonval obtains a powerful effect by using a bell magnet. The magnet *m m*, Fig. 662, is almost spherical; one of the poles has the cylindrical iron-piece *d* round which the induction coil *b b* is wound. The projection of the second pole has the form of a hollow cylinder, which surrounds the induction coil. The telephone by D'Arsonval weighs only 125 grammes, gives the words clearly and distinctly, and is said to surpass even Gower's telephone in force. In place of the usual speaking-funnel, a flexible tube is used, and in this manner sound disturbances are supposed to be overcome.

Böttcher's Telephone differs from other constructions by having the magnet so arranged as to be capable of vibrating; for this purpose it is suspended from fine steel loops. It can be moved upwards by means of the screw *a a*, Fig. 663; downwards by screw *a'*. The cores upon which the induction coils *b b* are fastened do not consist of one piece, but of three separate iron bars, an arrangement which facilitates the change of magnetism. The case of the telephone consists entirely of metal, because wood is more liable to change, and

to cause an alteration of the action of the magnet-poles towards the iron sheet. The tube *e*, which serves as a speaking-tube, is bent at an obtuse angle. The effect obtained with this instrument is very powerful; the sounds, however, are not so pure as in Bell's, Ader's, and other instruments. Böttcher's instrument would not answer in places which cannot be guarded from noises and disturbances.

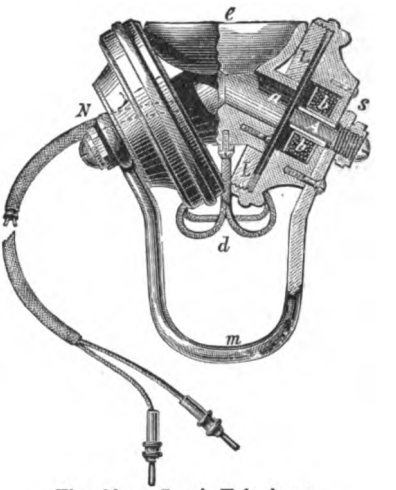


Fig. 664.—Gray's Telephone.

Just as it has been attempted to increase the efficiency of telephones by increasing the number of magnets or magnet-poles, so also several vibrating plates independent of each other have been used. A telephone with two plates has been constructed by Elisha Gray; it consists (as shown in Fig. 664) of two telephones placed at an acute angle. The horse-shoe magnet N *m* S has cylindrical shoes A at its poles, which are surrounded by the induction coils *b b*. Each shoe has a sheet of iron opposite to it, but the speaking-tube *e*, which terminates in the tubes *a*, serves for both membranes. The connection of the coils is shown at *d*; L L is the lid that covers the disc.

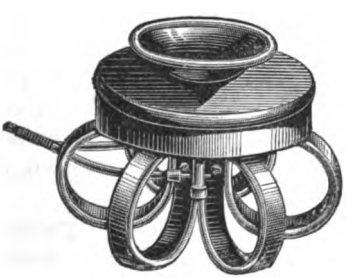


Fig. 665.—Phelps' Crown Telephone.

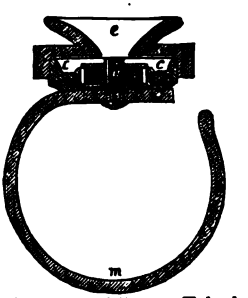


Fig. 666.—Phelps' Ponny Telephone.

Phelps' "crown" instrument is shown in Fig. 665. It has only one iron disc *c c*, opposite to which the similar poles of six ring-shaped magnets are placed; the remaining poles are bent against the edge of the disc. Phelps' double instrument consists of two telephones, such as described above, which are united to each other in such a manner that the two discs stand parallel to each other. The speaking-tube terminates in the space between the two discs. It was found, however, that the same results can be obtained with telephones of simpler construction. Phelps therefore constructed the instrument shown in

Fig. 666, which is known as the Ponny Telephone, and which differs little in reality from Bell's construction.

We here conclude the description of telephones the effect of which is due to magnetic changes, especially as a comparison of many later inventions with Bell's instrument shows no noteworthy alteration, and certainly no improvement; for although some of the instruments described surpass Bell's instrument in effect, none of them has surpassed or even reached the soft and precise accentuation of it. Here, as in the construction of other machines, new constructions are frequently made simply to obtain new patents, without regard to improvement of effect. The efficiency of a telephone depends less upon the insignificant alterations of a manufacturer, than upon the careful and exact workmanship with which the parts must be fitted.

Working the Telephone.—There is a great difference in the power of different voices to work the telephone. Shouting in it is of no use. The intonation must be clear, and the articulation distinct, and the style of conversation approach more the sing-song. The vowel sounds always come out the best; the palatal sounds *c*, *g*, *j*, *k*, and *q* the worst; in fact the latter sounds are frequently lost. The ear also requires a certain education, and the power of hearing varies surprisingly with different ears and with different people. Singing always comes through with great distinctness.

Other Applications.—No instrument is so delicate as the telephone for the detection of small and sudden currents. It is admirably adapted for showing the currents of induction set up in contiguous coils. If reversals or intermittent currents be sent through one spiral, while the other be gradually removed away, the rapidly diminishing effect of increased distance is very evident; indeed, all the phenomena of magneto-electric inductions are strikingly shown by its means. It enables us to test the resistances of short lengths of wire, and to adjust condensers with great accuracy. Mr. W. H. Preece, of the English Post Office and the Society of Telegraph Engineers, has communicated some interesting results of observations with the telephone, bearing on these points, from which we extract the following:

"The telephone explodes the notion that iron takes time to magnetise and time to demagnetise.* If time were occupied in magnetising, notes would be changed or lost; but they are not altered. The notion of time is due to the action of induction in coils producing *reaction* and *extra currents*. This is proved by the insertion of an electro-magnet or of coils of wire in a telephonic circuit. While it is possible to speak through a cable 100 miles long laid out straight in the sea, it is impossible to speak through 20 miles when coiled in a tank.

"Its delicacy has detected the presence of currents in wires contiguous to wires conveying currents, which have always been suspected, but have been evident only on wires running side by side for several miles (say 200) on poles or in well-insulated cables. In fact, the most delicate apparatus has

* This statement is far too sweeping.—ED.

hitherto failed to detect the presence of these currents by induction in short underground wires; but the telephone responds to these currents when the wires run parallel for only a few feet. Thus between one floor and another floor, at the General Post Office, it has been impossible to converse by means of the telephone through a wire, owing to the presence of these currents of induction from the innumerable working wires contiguous to it; and through some of the underground pipes of the streets of London, sounds are inaudible when the wires are working. In fact, two small-sized gutta-percha'd wires, *one foot long*, were lashed side by side; and when battery currents were sent through one, induction currents were distinctly heard on a telephone fixed on the other.

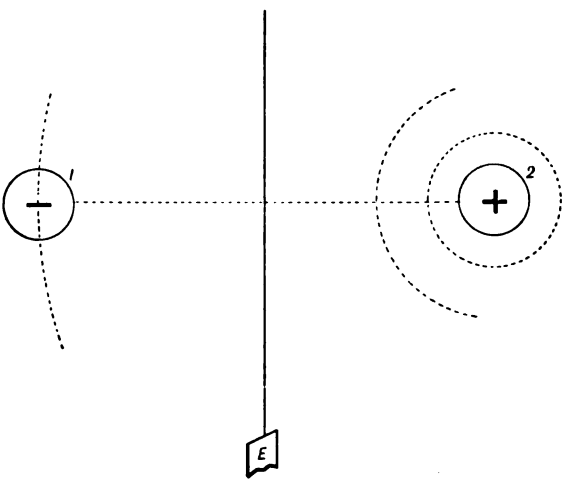


Fig. 667.—Screening the Wire from Induction.

Indeed this induction between wire and wire has proved the most serious obstacle to the practical introduction of the instrument. But it is not altogether irremediable on underground wires; it can be surmounted in three ways: 1. By increasing the intensity of the transmitted currents so as to overpower the currents of induction, and by reducing the sensitiveness of the receiving apparatus so as to make the instrument insensible to currents of induction, though responsive to telephonic currents. 2. By screening the wire from the influence of induction. 3. By neutralising the effects of induction.

"1. Mr. Edison in America has partially succeeded in effecting the first cure.

"2. I have overcome the second difficulty in a way that will now be described. Let 1 (Fig. 667) be a wire used for telephonic purposes, and 2 be an ordinary telegraphic wire contiguous to it. Let us regard 1 and 2 as symmetrical and contiguous particles of the two wires. If a current flow through 2 it will affect 1 inductively both statically and magnetically. Let us regard the static effect

first. If the current flow away from us, then we may consider the particle 2 as charged positively; lines of electric force will radiate all around it, and that line which passes through 1 will inductively charge that particle ***negatively.*** This influence being felt all along the wire, a current in the reverse direction to that in 2 will flow through 1. The reverse would occur if we assumed the primary current to flow in the other direction. Hence, an induced current will flow through 1, whenever the current in 2 commences and whenever it ceases. Now, if we place between 1 and 2 a screen of metal, or other conducting matter, in connection with the earth E, then the line of electric force, instead of passing through 1, will terminate at the screen. Hence, if we surround the wire 2 with a covering or sheath of metal, or if we submerge it in water, all effects of static induction will cease between 1 and 2. In water they are not entirely eliminated, for water is a very poor conductor; but they are so reduced by its influence, as my experiments between Manchester and Liverpool and between Dublin and

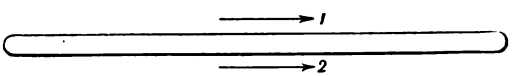


Fig. 668.—Neutralisation of Induction.

Holyhead have shown, that, if the water or wet serving had been a perfect conductor, they would have been removed as far as regards static induction.

"But we have to regard magnetic induction as well. Besides establishing a field of electric force around 2, a current flowing through that wire establishes a magnetic field around it, whose lines of force are circles, and whose directions are at right angles to the lines of electric force. Let us regard that line of force cutting 1. Each time a current commences, and each time it ceases, in wire 2, a line of magnetic force cuts wire 1, and produces in that wire a current of induction in the same direction as that produced by static induction. Now, if we make the screen of iron, those lines of force terminate in the iron, and wire 1 is freed. Hence, if we sheathe the wire 1 with iron, it is not only freed from the effects of static induction by being surrounded by a conductor in contact with the earth, but it is shielded from the effects of magnetic induction by its sheath of iron. Hence both effects of induction are entirely removed.

"3. They can be neutralised by means of a return wire, using this return wire instead of the earth. If 1 and 2 (Fig. 668) be two wires running side by side, then the current set up by induction from neighbouring wires in one wire is neutralised by the currents set up in the other side.

"But this assumes either that the disturbing wires are at an infinite distance from 1 and 2, or that 1 and 2 are infinitely near each other. All attempts to use return wires on existing poles, in cables, or in underground wires have utterly failed to do away with inductive disturbance; but Mr. Bell has had a

single gutta-percha wire carrying two conductors made, which very nearly fulfils the conditions and gives excellent results.

"The extreme delicacy of the instrument has introduced a disturbance from another cause, viz. leakage. Wires on poles are supported by glass, porcelain, and earthenware insulators; but the best support that was ever devised is but a poor insulator in wet weather. Currents escape over their surface from the wire they support, and these leakage currents find their way into telephonic circuits. Hence a telephone circuit which may work well in dry fine weather, may prove absolutely unworkable in wet weather.

"Another source of trouble arises from what are technically called 'bad earths.' It is almost impossible to make a perfect connection with the earth. There is always some resistance at that point; so that if two wires terminate on the same earth-plate, the one being a working circuit and the other a telephone circuit, some currents from the former are sure to pass through the latter and disturb the telephone. A return wire perfectly cures this evil.

"There are other disturbing elements that are peculiar. Earth-currents, which are always present in the wires, produce a peculiar crackling noise, similar to that produced by a current from a single-fluid battery, such as a Smee or a Leclanché, not unlike the rushing of broken water. This is due to the polarisation of the earth-plate, as the sounds produced by a battery current are due to the polarisation of the negative plate. When auroras are present these earth-currents become very powerful, and the sounds are much intensified. The effects of thunderstorms are very peculiar: a flash of lightning, even though so distant as to be out of sight, will produce a sound; and if it be near enough to be only sheet lightning, it produces, according to Dr. Channing, of Providence, a sound like the quenching of a drop of melted metal in water, or the sound of a distant rocket. Moreover, he says that this sound is heard before the flash is seen, proving the existence of some inductive effect in the air prior to the actual discharge. The telephone thus becomes an admirable warning of the approach of a thunderstorm.

"Sometimes a peculiar wailing sound is heard, which an imaginative correspondent of mine likened to 'the hungry cry of newly-hatched birds in a nest.' Mr. Preece thinks this is due to the swinging of the wires across the magnetic lines of force of the earth. It is not difficult to conceive that these vibrations may succeed each other in the necessary rhythmic order to produce musical tones. The wires are never free from sound; and every change of temperature or of the electric condition of the atmosphere is recorded on this delicate apparatus.

"The expansion of the iron diaphragm under the influence of the warm and damp breath when the telephone is first raised to the lips preparatory to talk, is very marked; it produces a faint rustling shiver.

"Immediately on the introduction of the instrument, great anxiety was felt to learn its performance on submarine cables. A telephone was sent to Guernsey, and another to Dartmouth, those two places being connected by a

cable sixty miles long. Conversation was carried on, the articulation being perfect, though slightly muffled. This was a surprise; for it was thought that the static induction of a cable, by its retarding influence, would have prevented articulation by lengthening the waves of electricity and rolling them up as it were. I was able to repeat these experiments on an artificial Atlantic cable, constructed to duplex the direct United States cable. There was no difficulty in speaking up to 100 miles, though the muffling effect of induction was evident. Beyond this distance up to 150 miles, muffling commenced to seriously impede conversation, and the sounds diminished considerably in strength : it was like talking through a thick respirator. The effect diminished rapidly up to 200 miles, beyond which articulation became impossible, though singing was distinctly heard; indeed, singing was heard through the whole length of the cable, 3,000 miles long; but this was traced to a secondary cause, it being due to the induction of condenser on condenser. Nevertheless, there is no doubt that singing can be heard through a much greater length than speaking, due to the greater regularity of the successive waves of electricity."

Mr. Preece subsequently experimented on the underground wires between Manchester and Liverpool, a distance of about thirty miles, and through this length had no difficulty whatever in speaking. Again, between Dublin and Holyhead, through the cable sixty-seven miles long, persons spoke with ease, singing coming through with remarkable power and effect. This cable contains seven distinct conductors. When one wire was used for the telephone, the sounds could be heard on every other wire, but in a feebler degree. When the other wires were working with the ordinary telegraphic apparatus, induction was evident, but not sufficiently intense to stop conversation. Each wire would be surrounded with a wet serving of hemp, but this was not of sufficient conducting power to entirely screen the effect of induction. The same effect was experienced between Manchester and Liverpool, where the wires are made up into cables of seven conductors, served outside with tarred hemp.

BATTERY TELEPHONES AND MICROPHONES.

In the preliminary remarks regarding telephony, it has been mentioned that Bell's instrument does good service, both as a sender and a receiver, provided that the sending and receiving stations are not too far from each other. The induced curents generated in the sender are only weak, and are still further weakened by the resistance of a long line, by leakages, etc. To avoid the use of such weak currents, battery telephones or microphones have been constructed (a distinction is sometimes made between a battery telephone and a microphone, but as both are based on the same principle, we shall here treat them together in the same chapter). The suitability of carbon for the construction of such instruments was first observed by Edison, and therefore, without paying attention to the older forms, or first experiments, we shall at once give a description of *Edison's carbon telephone.*

Edison's Carbon Telephone.—A representation of this instrument is shown in Fig. 669. The case of the sender consists of metal, and has an ordinary speaking-funnel, opposite to which is placed the membrane D. Behind the membrane is fastened a metal plate, upon which the carbon disc C rests. This disc is held in position by an ebonite ring. The surface of the carbon disc facing the membrane bears a platinum plate P, upon which the glass disc G is glued. This is connected with the membrane by means of the aluminium knob A, so that the vibrations of the membrane can be transmitted to the carbon C, and expose it to a pressure corresponding to the vibrations. A battery

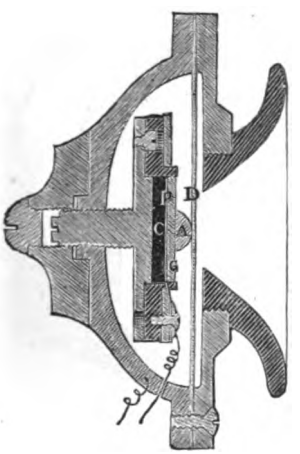


Fig. 669.

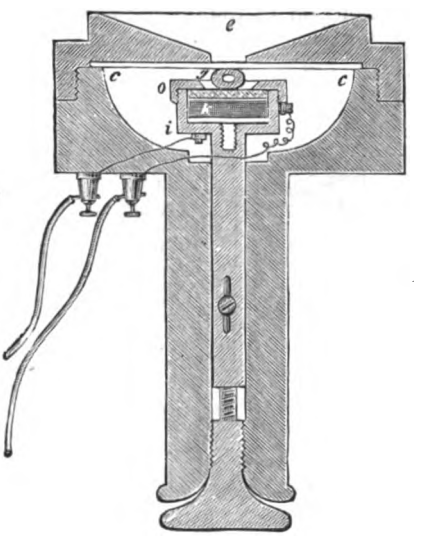


Fig. 670.

Edison's Carbon Telephones.

current sent through the carbon will therefore be converted into an undulation current owing to the change of pressure. When the plate D presses against the carbon, in consequence of the first or forward phase of its vibrations, the resistance of the carbon becomes less, and therefore the battery current flowing through it becomes stronger. The strength of the current diminishes when the pressure upon the carbon diminishes, by the return or second phase of the vibration of the plate, but a current of a certain fixed strength passes through the carbon when no pressure at all is exerted upon it, that is to say, when the plate or membrane is at rest. The current is conveyed through the carbon by having one of the battery wires connected with the metal case of the telephone, and the other with the platinum plate P.

Another construction by Edison is shown in Fig. 670. The centre disc K is placed between two platinum plates in a kind of box *o i*. The india-rubber tube *g* is placed between the membrane *c c* and an ivory disc, which rests

upon the upper platinum plate. Each of the platinum plates has a clamp for the wires. The vibrations of the membrane are transmitted by means of the tube and ivory plate to the upper platinum plate, and thence to the carbon. The screw at the end of the case serves to regulate the telephone.

Righi's telephone, which attained a certain reputation in 1878 in Italy, has little originality to recommend it, except its unusually large dimensions. The receiver consists of a Bell's instrument, with a straight and very powerful magnet, which has a membrane consisting of parchment, of corresponding size, opposite to it, and carrying in the centre a circular disc of sheet iron. The construction of the sender may be clearly understood with the help of Fig. 646,

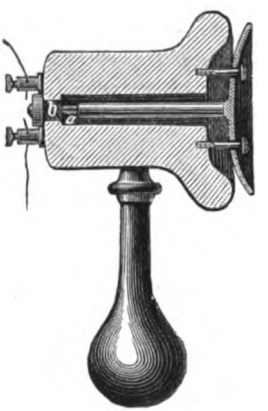


Fig. 671.—Ader's Electrophone.

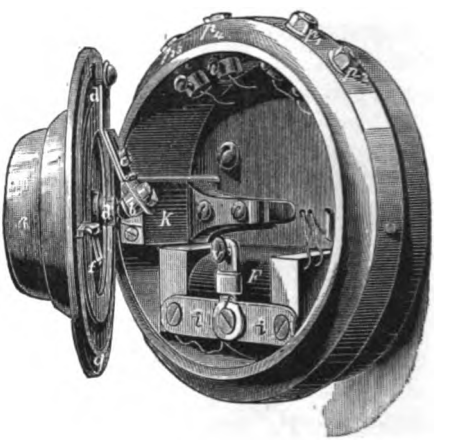


Fig. 672.—Berliner's Microphone.

if we imagine the little bar dipping in the fluid to be furnished with a thin metal plate, and a mixture of graphite and silver powder to be substituted for the fluid. The pressure upon the powder will change with the vibrations of the membrane, and the battery current sent through the powder will thus become an undulation current.

Ader, who constructed a receiver similar to the one described, used the apparatus shown in Fig. 671, and called it "Ader's electrophone." A wooden frame, which has a handle attached, carries a carbon cylinder *a*, fastened to a wooden pin, at the other end of which is the sound-reflector. The rounded end of the carbon cylinder rests upon the carbon piece *b*, which is connected with one of the clamps, the second clamp being connected with the carbon cylinder itself.

Fig. 672 represents Berliner's microphone or transmitter. The most important portion of the apparatus, viz. the changeable carbon contact, is formed by the two carbon pieces *a* and *b*; the former is fastened in the middle of the

thin iron disc, which is attached to the lid of the microphone; the second is placed at *c*, in the catch, which is hung from the movable arm *d*. The contact of the two carbon pieces is brought about by the weight of the carbon piece *b*. The support *d* serves also to maintain the iron disc in its position when the lid is opened. When in use, the poles of this sender p_1 and p_2 are connected with the poles of a battery (usually a Leclanché element); the current then flows from clamp p_1 through the metal piece K, to *d* and *c*, and so to the carbon pieces *b* and *a*; thence it returns through the spring *f'*, the screw V, through the primary coil of the induction coil F, thence to the clamp p_2, and so back again to the battery. The clamps p_3 and p_4 hold the wires of the secondary coils, and are connected with the line or earth. If the iron disc is made to vibrate by sound-waves, the two carbon pieces *a* and *b* will also

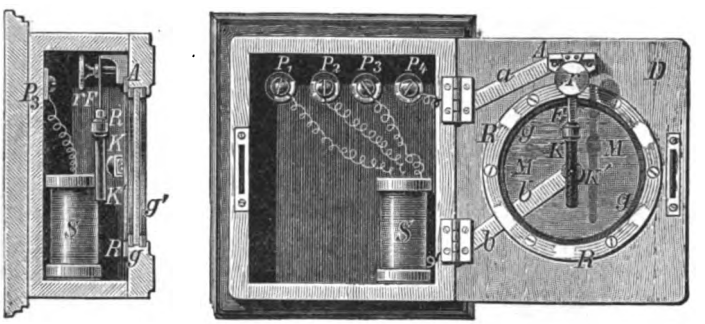


Fig. 673.—Heller's Transmitter.

vibrate, causing those alterations of contact which convert the battery current into an undulation current. Every well-acting telephone can be connected with Berliner's microphone as receiver. If the sending and receiving stations are very far from each other, and a considerable resistance in the wires has to be overcome, Berliner makes use of microphones with three contacts.

F. Heller's transmitter, as shown in Fig. 673, is a little different from Berliner's transmitter. The lid D of the box has a circular hole in it, in which a disc M M of wood (deal) is placed as membrane; the india-rubber tube *g g* is placed over it, and over this is screwed the brass ring R R in order to hold the whole in position. The carbon cylinder K' is fastened to the spring F, and the latter is fastened to A. The contact between the carbon cylinder K' and carbon knob K is regulated by the adjusting screw V. The metal piece A is connected with clamp P_4 by means of a metal strip *a* and a short wire. The carbon knob K is connected with the primary coil of the induction apparatus S by means of the strip *b b*. The second end of this wire is connected with the clamp P_3. The wire ends of the secondary spiral are fastened to the clamps P_1 and P_2. When clamps P_3 and P_4 are connected with the poles of a battery,

the current flows from clamp P_4 through *a* A F, the carbon cylinder K′, the carbon knob K, brass strip *b b*, through the primary coil of the induction coil, through clamp P_3, and so back again to the battery. When the membrane M M is made to vibrate, the battery current becomes a primary undulation current, inducing in the secondary coils undulating induced currents, which are conveyed through clamps P_1 and P_2 to the receiving apparatus.

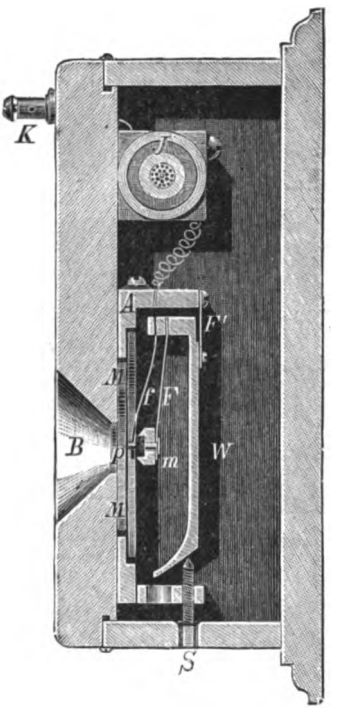


Fig. 674.—Blake's Microphone.

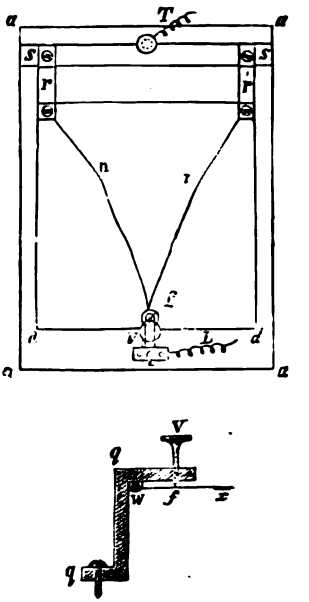


Fig. 675. – Locht-Labye's Pantelephone.

The microphone by F. Blake differs from others in this respect:—that none of the contact-pieces are fastened to the membrane, and this prevents disturbances due to contraction or expansion of the membrane. The iron sheet M M is placed opposite B (Fig. 674), between pads of india-rubber tubing. One of the contact-pieces, consisting of a small platinum cylinder *p*, is fastened to the spring *f*, which presses it against the second contact-piece; a carbon disc (shown in the figure as a black rectangle) is set in the metal piece *m*, and carried by the spring F, which presses both carbon and platinum cylinder against the iron disc. The regulation of the contact is brought about in the following manner:—The spring F is fastened to the plate W, which is again held by the spring F′, which is screwed to the fixed clamp A. The screw S presses

against the inclined plane of W, and, by being turned in one or the other direction, effects the regulation. Blake's transmitter is, as a rule, used with a Leclanché element. The current passes as follows: Through the clamp K into the primary coil of the induction apparatus J, through the spring *f* into the platinum cylinder *p*, through the carbon at *m* into F, through W to S, and then back to the battery.

A very sensitive microphone, called by the inventor a Pantelephone, and shown in Fig. 675, was constructed by L. de Locht-Labye. The receiving apparatus reproduces conversations held at a distance of 20 metres from the microphone perfectly distinctly. A plate of either cork, wood, or sheet metal of a rectangular shape, 10 centimetres wide and 15 centimetres long, is suspended from the metal beam S S, which is held by the steel springs *r r*; at its lower edge at *f* it carries a carbon disc, which leans against the silver plate X. This silver plate is fastened to the spring *f*, which is fixed at W. The screw V regulates the contact. The battery current passes through the wire L, *q*, through the spring *f*, and the silver contact, through the wires *n n* and springs *r r*, and returns through T to the battery. When sound-waves make the plate vibrate the contact becomes changeable, and thus produces undulation currents, which generate undulating induced currents in an induction apparatus, and thus reproduce the sound-waves at the receiving station.

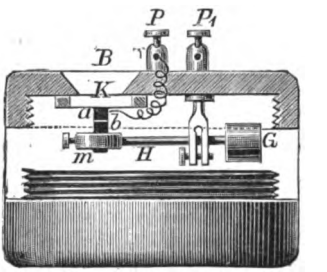


Fig. 676.—Wreden's Phonophore.

The Phonophore, by Wreden, is shown in Fig. 676. It consists of a cork plate K, which carries a contact *a*, connected with the clamp P by means of a short wire. The second contact *b* is placed on one end of the lever G H *m*, which has a counter-weight at its opposite end. The pressure of the contact between the two pieces *a* and *b* is regulated by the weight G. Wreden constructed microphones also of six and more contacts. The current passes in the microphone shown in the figure as follows:—From the clamp P to the contact-pieces *a* and *b*, through the lever *m* H, and through the clamp P_1 back to the battery.

Microphones with several contacts have been constructed by Crossley, Ader, and Gower. All three make use of a rectangular plate of wood as a membrane. This plate, as a rule, is fastened in the opening of a strong wooden frame, forming with it a box shaped, in Crossley's instrument, like a writing-desk, the inside of which contains the carbon contacts. These consist of four carbon rods, which rest with their ends upon carbon blocks, as shown in Fig. 677. The connection of the carbon contacts with the battery is brought about by metal strips, fastened to the carbon blocks. Ader arranges eight or ten carbon rods, as shown in Fig. 678, B C D. Ader, who had undertaken the transmission of the opera music to the Palace of Industry during the Exhibition in 1881, placed his microphones upon leaden plates P, in order to prevent interruption or disturbance of the music transmitted from the voice of the singer by footsteps on the floor, etc.

Boudet and others have also constructed microphones of several contacts, some arranged parallel and others in series; the latter arrangement is shown in Fig. 679. A glass tube R, of 7·5 centimetres in length and 1 centimetre in diameter, is fastened to a joint upon a stand. The supports T T carry the sounding-tube B, which has on the outer side an ordinary mouthpiece, and on the inner side a narrow opening, opposite which is placed the membrane *m m*, made of gutta-percha. The copper cylinder K, which is connected with the membrane, reaches

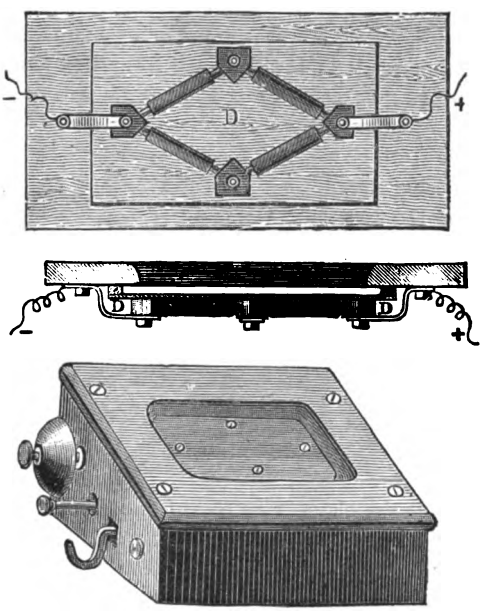


Fig. 677.—Crossley's Transmitter.

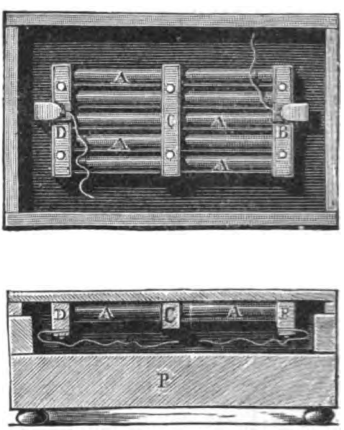


Fig. 678.—Ader's Transmitter.

a short distance into the glass tube, and touches the first of the six carbon balls in it. In the other end of the glass tube is placed the metal piece A, which carries the apparatus for the regulation of the carbon contacts. By turning the screw S in the one or the other direction the cylinder C, along with F and K′, moves forward or backward, thus diminishing or increasing the force of contact between the carbon balls.

Professor Hughes's Explanation of the Action of the Microphone.—Professor Hughes, the inventor of the microphone, has given some interesting particulars respecting the physical action of the instrument. He states the problem he sought to solve by the microphone as follows: To introduce into an electrical circuit an electrical resistance, which resistance shall vary in exact accord with sonorous vibrations, so as to produce an undulatory current of electricity from a constant source, whose wave-length, height, and form shall be an exact

representation of the sonorous waves. In the microphone we have an electric conducting material, susceptible of being influenced by sonorous vibrations; and thus we have the first step of the problem.

The second step is one of great importance, and was solved by the discovery that when an electric conductor in a divided state, either in the form of powder, filings, or surfaces, is put under a certain slight pressure, far less than that which would produce cohesion, but *more than would allow it to be separated by sonorous vibrations*, the following state of things occurs: The molecules at these surfaces

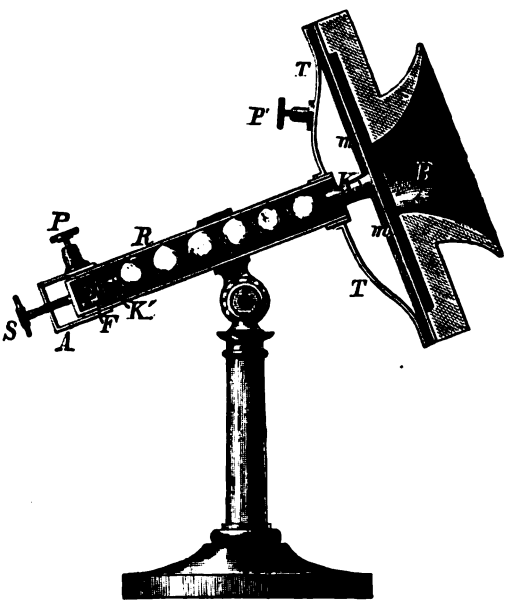


Fig. 679.—Boudet's Microphone.

being in a comparatively free state, although electrically joined, do of themselves so arrange their form, their number in contact, or their pressure, that the increase and decrease of the electrical resistance of the circuit is altered in a very remarkable manner, and to an extent that is almost fabulous.

It is only necessary to observe certain general considerations to produce an endless variety, each having a special range of resistance.

The tramp of a fly, or the cry of an insect, requires little range, but great sensitiveness; and two surfaces, therefore, of chosen materials, under a very slight pressure, such as the mere weight of a small superposed conductor (Figs. 650 and 651) suffice; but it would be unsuitable for a man's voice, as the vibrations produced by the voice would be too powerful for the instrument, and would, in fact, produce interruption of contact amounting to "make and break."

Pine-wood is the best resonant material we possess, and it preserves its

structure and quality when converted into charcoal. A man's voice requires the contact of four surfaces of pine-charcoal. The number of surfaces and the materials have to depend on the range and power of the vibrations, and the surfaces must be pressed together by a force that varies with the force of the sonorous vibrations. Thus, for a man's voice the surface must be under a far greater pressure than for the movements of insects. In order to test whether the pressure is sufficient to admit of a perfect undulatory current being produced by the sonorous vibrations of the range of the voice or sounding body employed, it is well to place a galvanometer in the circuit; while speaking to the microphone transmitter the needle should not be deflected, as the waves of + and − electricity are equal, and are too rapid to disturb the needle. If the pressure on the materials producing the microphonic contacts is not sufficient, we shall have a constant succession of interruptions of contact, and the galvanometer needle will indicate the fact. If the pressure on the materials is gradually increased, the tones will be loud, but wanting in distinctness, while the galvanometer indicates interruptions in the current. By further increasing the pressure the tone becomes clearer, and the needle of the galvanometer will just be stationary when a maximum of loudness and clearness is attained. If the pressure be further increased the sounds become weaker, though they remain clear, and on still gradually augmenting the pressure the sounds die out, until a point arrives at which there is silence.

The simplest form of microphone employed by Professor Hughes in his theoretical investigations consisted of a flat piece of charcoal, 2 millimetres thick and 1 centimetre square, connected with a copper wire, and glued to a board or block of wood. Upon this piece one or more similar pieces were superposed, the upper piece being connected with a wire. The required pressure was put on the blocks. Professor Hughes thus reasons out the nature of the molecular action:

"Let the lower piece be called A, and the upper B; when we subject the board to sonorous vibrations we cannot imagine in the charcoal an undulatory movement of the actual wave-length of the sonorous wave, for that would be several feet; nor can we imagine a wave of any length without admitting that the force must be transmitted from molecule to molecule throughout the entire length. How is it that the molecular action at the surfaces of A and B so vary the conductivity or electrical resistance as to throw it into waves in the exact form of the sonorous vibrations? It cannot be because it throws up the upper portion, making an intermittent current, because the upper portion is fastened to the lower, and the galvanometer does not indicate any interruption of current whatever. It cannot be because the molecules arrange themselves in stratified lines, becoming more or less conductive, as then surfaces would not be required, that is, we should not require discontinuity between the blocks A and B; nor would the upper surface be thrown up if the pressure be removed, as sand is on a vibrating glass. The throwing up of this upper piece B when pressure is removed proves that a blow, pressure, or upheaval of the lower por-

tion takes place: that this takes place there cannot be any doubt, as the surface considered alone (having no depth) could not bodily quit its mass. In fact, there must have been a movement to a certain depth; and I am inclined to believe, from numerous experiments, that the whole block increases and diminishes in size at all points, in the centre as well as the surface, exactly in accordance with the form of the sonorous wave. Confining our attention, however, to points on A and B, how can this increased molecular size or form produce a change in the electrical waves? This may happen in two ways: *first*, by increased pressure on the upper surface, due to its enlargement; or, *second*, the molécules themselves, finding a certain resistance opposed to their upward movement, spread themselves, making innumerable fresh points of contact. Thus an undulatory current would appear to be produced by infinite change in the number of fresh contacts. I am inclined to believe that both actions occur; but the latter seems to me the true explanation; for if the first were alone true, we should have a far greater effect from metal powder, carbon, or some elastic conductor, such as metalised silk, than from gold or other hard unoxidisable matter; but as the best results as regards the human voice were obtained from two surfaces of solid gold, I am inclined to view with more favour the idea that an infinite variety of fresh contacts brought into play by the molecular pressure affords the true explanation. It has the advantage of being supported by the numerous forms of microphone I have constructed, in all of which I can fully trace the effect.

"I have been very much struck by the great mechanical force exerted by this uprising of the molecules under sonorous vibrations. With vibrations from a musical box 2 feet in length, I found that one ounce of lead was not sufficient on a surface of contact 1 centimetre square to maintain constant contact; and it was only by removing the musical box to a distance of several feet that I was enabled to preserve continuity of current with a moderate pressure. I have spoken to forty microphones at once, and they all seemed to respond with equal force. Of course, there must be a loss of energy in the conversion of molecular vibrations into electrical waves; but it is so small that I have never been able to measure it with the simple appliances at my disposal. I have examined every portion of my room—wood, stone, metal, in fact all parts—and even a piece of india-rubber: all were in molecular movement whenever I spoke. As yet I have found no such insulator for sound as gutta-percha is for electricity. Caoutchouc seems to be the best; but I have never been able by the use of any amount at my disposal to prevent the microphone reporting all it heard.

"The question of insulation has now become one of necessity, as the microphone has opened to us a world of sounds, of the existence of which we were unaware. If we can insulate the instrument so as to direct its powers on any single object, as on a moving fly, it will be possible to investigate that object undisturbed by the pandemonium of sounds which at present the microphone reveals where we thought complete silence prevailed.

"I have recently made the following curious observation: A microphone

on a resonant board is placed in a battery circuit together with two telephones. When one of these is placed on the resonant board, a continuous sound will emanate from the other. The sound is started by the vibration which is imparted to the board when the telephone is placed on it; this impulse, passing through the microphone, sets both telephone discs in motion; and the instrument on the board, reacting through the microphone, causes a continuous sound to be produced, which is permanent so long as the independent current of electricity is maintained through the microphone. It follows that the question of providing a *relay* for the human voice in telephony is thus solved.

"The transmission of sound through the microphone is perfectly duplex; for if two correspondents use microphones as transmitters, and telephones as receivers, each can hear the other, but his own speech is inaudible: and if each sing a different note, no chord is heard. The experiments on the deaf have proved that they can be made to hear the tick of a watch, but not, as yet, human speech distinctly; and my results in this direction point to the conclusion that we only hear ourselves speak through the bones, and not through the ears.

"However simple the microphone may appear at first glance, it has taken me many months of unremitting labour and study to bring it to its present state through the numerous forms, each suitable for a special object."

Professor Hughes throughout his investigations used a Bell's telephone as receiver, and admits that it was owing to the discovery of that sensitive instrument that he was able to follow up his researches.

TELEPHONES AND MICROPHONES OF SPECIAL CONSTRUCTION.

The iron wire telephone of Ader is of theoretical interest. Ader tried to construct a telephone without a membrane; for this purpose he used iron cores of different strength. He obtained the best results with very thin iron cores, *i.e.* iron wires. Fig. 680 shows one of these forms of apparatus; it consists of a board B, through which the iron wire E is pushed and bent at *e*. This wire is surrounded by the coil S, which is wound upon a quill F. K is a massive piece of copper, which is soldered to the free piece of the wire. When in use the leading wires of this apparatus are connected with the clamps P P', and the ear is placed at *e*. Words spoken into a distant telephone are clearly heard when the apparatus is 10 or 15 centimetres from the ear. Ader also gave his iron wire telephone the form shown in Fig. 681. The iron wire *m* is partly soldered to the massive copper piece *f*, and partly to the copper piece *d*, which again is connected with the copper piece *g*. The upper copper piece closes the upper opening of the tube which encloses the whole apparatus, and is connected with *e* by means of a screw. The sounding-tube *e* is similar to that in Bell's telephone, but has no central opening. The copper pieces *d g* form a cylinder, which almost entirely fills the tube, but is separated from the walls by an india-rubber tube placed over it. The insulated wires *c* and *o* are passed through the copper pieces, and form the ends of the induction coil which surrounds the iron wire

at *b*. The tube is closed at its lower end by the ebonite disc *i*, to which the two clamps are fastened. The manner of working of the two telephones last described may be explained, according to Th. du Moncel, in the following manner: It has been mentioned that the words reproduced by a Bell telephone are due to the undulation currents which are collected in the receiver, and which cause

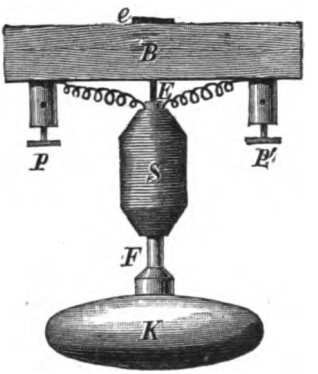


Fig. 680.—Ader's Iron Wire Telephone.

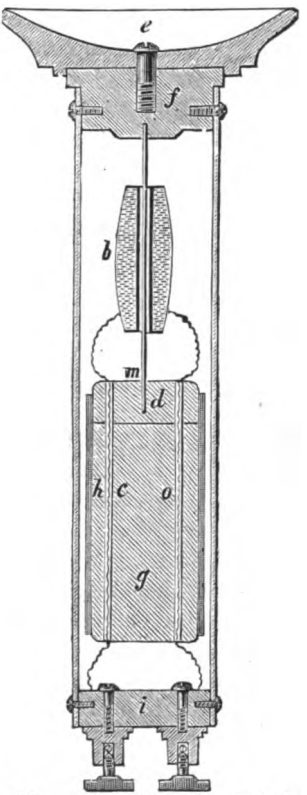


Fig. 681.—Ader's Iron Wire Telephone.

its iron disc to vibrate in exactly the same manner as the sound-waves cause the iron disc of the sender to vibrate. This explanation, however, is not complete; it still leaves the question unanswered: Of what kind are the vibrations which the iron disc makes? Does the disc vibrate as a whole with transversal vibrations, or do the different iron particles vibrate with molecular vibrations only? Th. du Moncel argues that it is molecular vibration which takes place. Ader constructed the telephones which are described above for the purpose of experimentally determining which of the two opinions is correct. He constructed a telephone without a membrane, that is, a telephone where transversal

vibrations cannot take place. As he succeeded in his experiments, he became of Th. du Moncel's opinion, for he proved by them that the reproduction of sound-waves is not *exclusively* due to transversal vibrations. According to Th. du Moncel, the mode of action of Ader's wire telephone is as follows: The undulation currents circulating through the coil *b* cause molecular vibrations in the iron wire. These act chiefly in a longitudinal direction, and spread more quickly than the vibrations of the heavy mass *d g*; the result is that the mechanical effect of the vibrations in the iron wire is greatly increased. The vibrations are then mechanically transmitted to the mass *f*, and spread from there as waves of sound through the sounding-funnel. Ader's iron wire telephone greatly resembles Reis's receiver (Fig. 641). The sounding-board is replaced by the copper mass, which takes part in the vibrations and increases their effect.

Fig. 682 represents Breguet's mercury telephone. The two vessels A contain mercury, over which acidulated water is poured, and into which pointed tubes B, nearly filled, are allowed to dip. The mercury in the tubes, as well as in the vessels, is connected by wires, as shown in the figure. The effect of the apparatus is based upon a physical fact discovered by Lippmann when sending currents of electricity through the mercury contained in capillary tubes. Lippmann observed that in every closed circuit electric currents are produced when the surface of the mercury is altered by mechanical means, and conversely that electric currents alter the surface of the mercury. Breguet's telephone is based upon these electric phenomena of capillary attraction. The tubes B B are closed by membranes, which are connected with the mouthpieces. When sound-waves impinge on the membrane of one part of the apparatus they mechanically affect the mercury, and produce electric currents, which travel to the second capillary tube; these cause a mechanical alteration of the mercury surface, making the membrane of the second apparatus to vibrate in the same manner as the membrane of the first, *i.e.* the waves of sound of the first apparatus are exactly reproduced in the second apparatus. Breguet's mercury telephone may be used with or without a battery; in the latter case a special arrangement of the mercury and water is necessary.

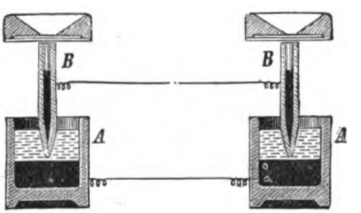


Fig. 682.—Breguet's Mercury Telephone.

The chemical telephone by Edison is based upon an electro-chemical phenomenon that has not, as yet, been sufficiently explained; but by using this very phenomenon he constructed, in 1872, the electro-motograph. The phenomenon in question is the following: If a metal plate be connected with the positive pole of a battery, and be covered with paper or any other porous body soaked in potash, and if a platinum or leaden point, connected with the negative pole of the battery, be drawn over the wetted surface, a certain resistance is felt as long as the current is broken, but as soon as the current flows through the

metal and the wetted surface this resistance disappears. The current is supposed to react electrolytically on the potash, and cause a thin gas layer between its surface and the pencil, which overcomes the resistance.

Fig. 683 represents the apparatus constructed by Edison on this principle. A metal spring *a* is fastened to the mica disc D, which is of about 10 centimetres diameter. One end of the spring, which has a platinum contact attached, slides upon a cylinder A, which moves in the direction indicated by the arrow. The surface of the cylinder consists of moist gypsum impregnated with potash and mercuric acetate. The spring *a* is connected with the negative pole of a battery, the cylinder with the positive pole of a battery; some kind of transmitter is also inserted in the circuit. When the circuit is broken the friction between the spring *a*

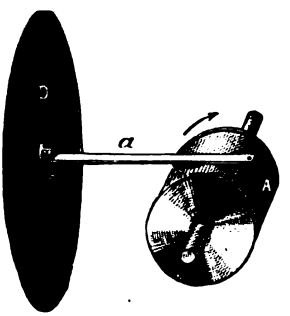
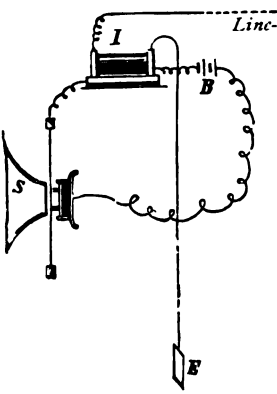


Fig. 683.



Edison's Chemical Telephone.

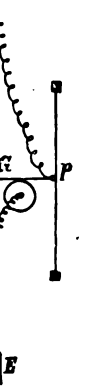


Fig. 684.

and the cylinder A will cause the former to be taken along with the latter so far as the elasticity of the mica plate D permits. When the circuit is made again the friction ceases, and the disc and spring take up their original position again. When the making and breaking of the current follow each other, or when alterations in the current take place, the resistance between *a* and A will also vary in an oscillating manner, and the mica plate D will therefore begin to vibrate. If the current variations are caused by speaking before the transmitter, the mica plate will reproduce the waves of sound. Fig. 684 shows the arrangement of this chemical telephone system. S represents the carbon transmitter, which, together with the primary coil of the induction coil I, and the battery B, forms a circuit. The secondary spiral is connected on one side with the earth-plate E, and on the other with the spring G fastened upon the mica plate P. The gypsum cylinder, upon which the spring slides, is connected with the earth-plate E.

Dolbear succeeded in the construction of a receiver based on electrostatical principles. This receiver consists in its simplest form of two metal discs of about

5 centimetres diameter, which are placed parallel and near to each other, but in such a manner as not to touch each other; this is brought about by a frame of gutta-percha, which has grooves for holding the discs, as shown in Fig. 685. The gutta-percha fastening is screwed on the one side to a lid, which carries the mouthpiece C, and on the other side to a kind of knob H, which serves as a handle. The screw S is connected with the disc nearest to it, but as this disc is held by the gutta-percha fastening, and at the same time by the screw which passes through its middle, it cannot vibrate. The disc near the mouthpiece is, however, only fastened by its edges, and can be made to vibrate.

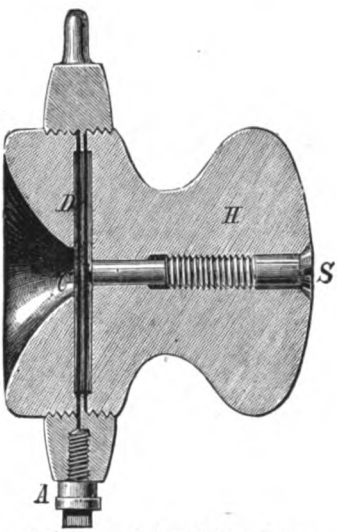


Fig. 685.—Dolbear's Receiver.

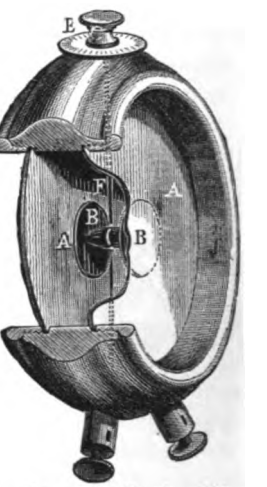


Fig. 686.—Dunand's Torsion Microphone.

The screw S not only prevents the first disc from vibrating, but also regulates the distance between the two discs. Each of the metal discs is connected with a clamp A. The clamps also receive the ends of a secondary coil of an induction apparatus, so that the two discs form, so to speak, the poles of an induction apparatus connected with a condenser, in which air represents the insulating layer between the plates. The two discs, therefore, receive opposite electrical charges, as soon as induced currents are generated by the induction apparatus. A series of induced currents will cause a series of charges, and as the opposite electrical charges of the two discs cause attraction between them every time they are produced, a series of attractions will be the consequence, *i.e.* the movable disc will be made to vibrate. These vibrations show themselves sufficiently powerful to be perceptible to the ear. If a sender of any construction be now inserted in the circuit of this apparatus, the induced currents will cause the free disc in Dolbear's apparatus to vibrate, and

it will do office as a receiver. The best results were obtained by using an induction coil which had a resistance of from 4,000 to 5,000 ohms. The electro-motive force of the induced currents reaches a considerable height, and the usual way of insulating the wires, as in telegraph lines, would not be sufficient. This, however, may be avoided by arranging the induction spiral near the receiver, instead of connecting it with the sender. The comparatively weak primary currents only will then be sent through the leads, and induced currents of high potential generated at the receiving station.

In Dunand's torsion microphone, Fig. 686, two thin iron plates A A′ are surrounded by a wooden ring, so as to form a kind of box. Inside this box

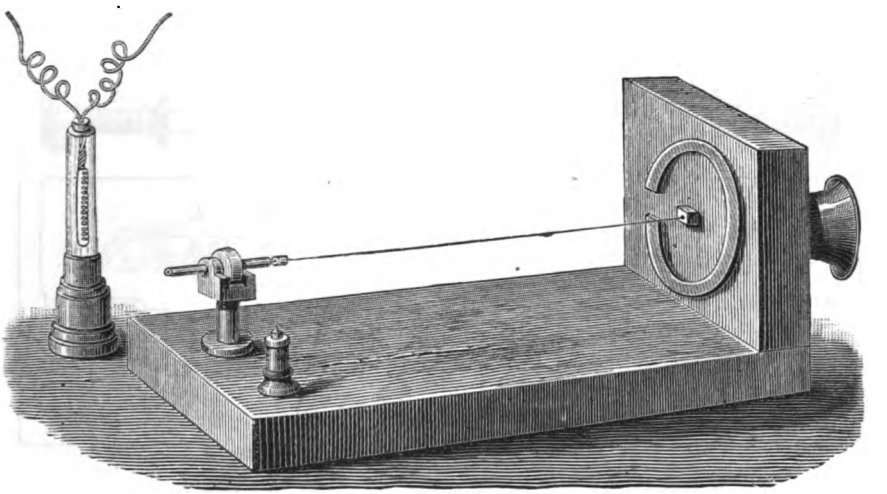


Fig. 687.—The Thermophone.

the carbon contacts, well protected from dust, etc., are placed. The two carbon discs B B are fastened in the middle of the iron discs, and a conical carbon piece of about 12 millimetres in length presses against them. One end of the wire F F, which is wound round the carbon piece, is fastened to the wooden frame, whilst the other end terminates in the knob E. The contacts may be altered by turning this knob, thus altering also the sensibility of the microphone; by having two membranes, two voices may be conveniently transmitted at the same time.

Ader reproduced speech, as already mentioned, by conveying wave-currents through a stretched iron wire connected with larger metal masses. Wildbrant showed that the reproduction succeeded also with wires of other material, when only the wave-currents were sufficiently strong. When Mr. Preece had experimentally convinced himself of the correctness of this fact, he constructed the apparatus shown in Fig. 687, on the plan of the thermophone described by

F. I. Pisko in his *Telephonie.* This instrument originally consisted of a thin platinum wire stretched between a membrane and an adjusting screw. The wave-currents which are conveyed through the wire, produce by their altering strength an undulating heat effect, which manifests itself by the contraction and expansion of the wire, that is, by the vibration of the membrane. In the latest form of the thermophone by Preece, a glass tube closed at the

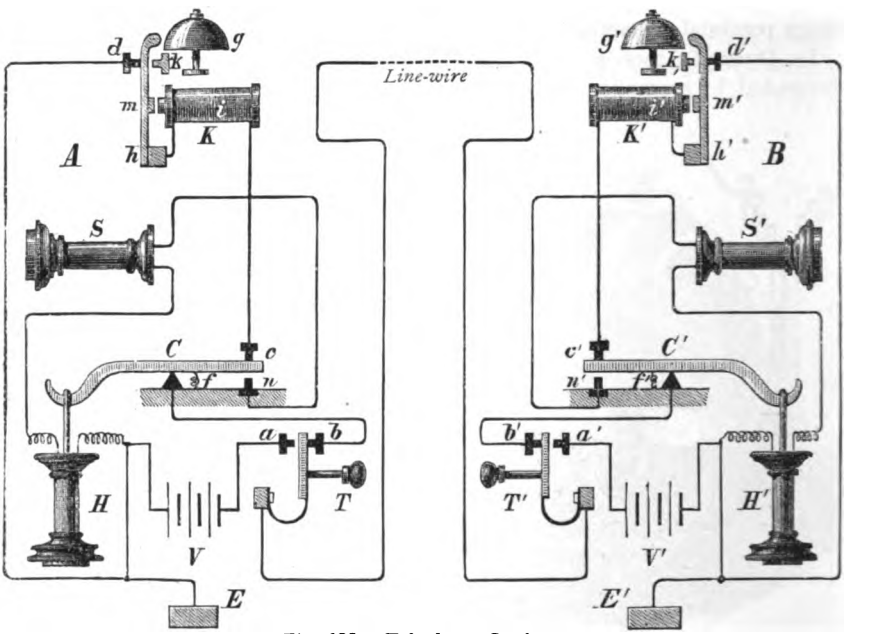


Fig. 688.—Telephone Stations.

end by a cork, as shown to the left of the figure, is employed. Two wires are passed through the cork, and between them is placed a platinum spiral. The undulating currents cause heat-waves in the latter, and, in consequence of this, the wire contracts and expands, and the air in the tube begins to vibrate. Up to the present, however, only feeble results by this action have been obtained.

TELEPHONE INSTALLATIONS.

A. DOUBLE STATIONS.

Fig. 688 shows the arrangement of magneto-electric telephones at the stations A and B. S S′ represent the sending apparatus; H H′ the receiving apparatus; K K′ bells; T T′ keys, and V V′ batteries: E E′ are earth-plates. If A wishes to communicate with B, the key T is first pressed down, and thus a contact is produced at *a*, closing the following circuit: V, *a*, T, through the line to station

B, T′, *b*′, lever C′, contact *c*′ to the bell K′, from here through contact *d*′ to the earth E′ E, and back to battery V. The bell K′ will therefore ring so long as T is held down at station A. The current flows through the bell arrangement in the following manner: First through the coils of the electro-magnet *i*′, then over *h*′ *d*′ to the earth. The magnet attracts the armature *m*′, which is fastened to the lever at *h*′, causing it to strike against the bell *g*′. At this moment the circuit is broken because the lever loses contact with *d*′, and therefore the electro-magnet lets go its armature *m*, which swings back into its original position, making contact again at *d*′, when the magnet will again attract the

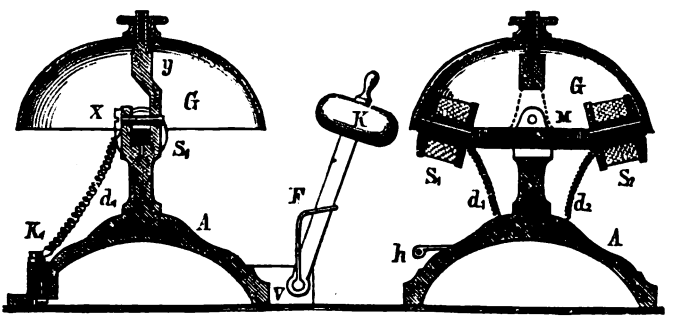


Fig. 689.—Weinhold's Bell.

Fig. 690.—The Resonator.

armature, etc. B returns the signal, pressing T′ down. By taking down the receiving instruments H and H′ from the levers C C′, contact is made at *n* and *n*′. Speaking at A generates wave-currents in S, which flow to the contacts *n*, *b*, T, through the line to T′, *b*′, C′, *n*′ and S′, to the receiver H′, returning again over E′ E, and the telephone H, back to S. The wave-currents generated at station B in the telephone S′ flow through the same circuit in the reversed direction. When communication is at an end the telephones H H′ are put in their places again, thus producing the original joining necessary for signalling. In practice, however, the same kind of magneto-electric apparatus is seldom used both for receiver and sender, for reasons mentioned already; as a rule, a microphone is used as a sender, and a magneto-electric telephone as receiver. The arrangement shown in Fig. 688 is very nearly the same when the telephones are taken off, except that two contacts will have to be made by the levers C C′, as there will now be two wave-currents, viz. the primary and the secondary.

Before we consider the practical execution of the arrangement shown in Fig. 688, we must describe some of the separate instruments included in the

various circuits. Bells of very simple construction, serving as call apparatus, have recently been constructed by Fein, A. Weinhold, and Abdank-Abakanowicz. The instrument constructed by Weinhold is shown in Fig. 689. The iron bell-shade G is screwed on to the upper end of the metal stand A; M is an electro-magnet, having its induction coils at S_1 and S_2; the rounded shoes of these are placed within the bell close to the edge. The induction coils are connected with each other, and also with clamps, to which the line-wires lead by the wires d_1 d_2. One of these clamps is visible at K_1. The wooden

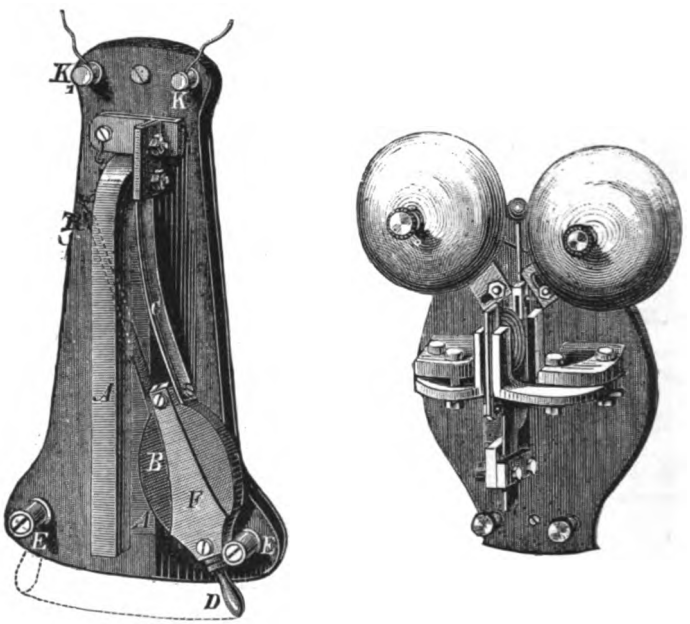


Fig. 691.—Abdank-Abakanowicz' Call Apparatus.

hammer K is fastened to the wooden piece V, and pressed against the bell by means of the spring F. If the hammer is allowed to fall upon the bell the latter will vibrate violently, and will cause the bell-edges alternately to approach and be removed from the induction coils and their pole-shoes, thus producing induced currents in the coils. When these currents reach the distant station they cause the telephone membrane to vibrate so violently, that the latter emits a sound, which is still further increased by means of a resonator, shown in Fig. 690. This resonator must, however, agree within half a tone with the bell.

The apparatus constructed by Abdank-Abakanowicz is shown in Fig. 691. The steel spring C is fastened to the horse-shoe magnet A A. This spring carries the induction coil B with its armatures at its lower end, by means of which the iron core inside the coil is shut off. When at rest the spring C stands parallel to

the plane of the magnet-arms and the coil exactly between the two arms. When the coil is made to leave this position by means of D (as shown in the figure), and then suddenly allowed to swing back, it will oscillate between the magnet-poles A A, causing induced currents of alternating direction in the coil; these currents are conveyed either through the spring C and the clamp K, or through the spiral R and the clamp K_1 to the bell of the distant station, which is a so-called polarised bell analogous in construction, as may be seen from the

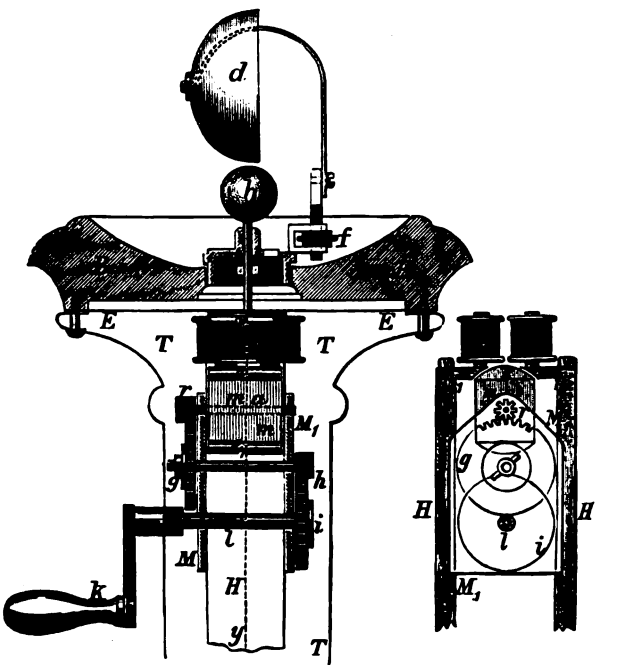


Fig. 692.—Münch's Call Apparatus.

figure, to the inductor apparatus, except that in place of the handle a ball fastened to a rod is used. Two horse-shoe magnets have their poles bent vertically upward, and a flat spring having a coil in its middle portion is fastened between them. When the alternating currents, generated in the induction apparatus, reach the coil, the flat iron spring will swing to the right and left, causing the knob to strike each bell alternately. Experiments have proved that the force of the currents generated in the induction apparatus is sufficient to ring a bell at a distance of 250 kilometres.

A. Münch took out a patent for a call apparatus which might easily be employed where telephones with horse-shoe magnets are in use. The horse-shoe magnet H H, with its shoes p_1 and p_2, is placed in the telephone frame T T (Fig. 692), and the induction coils S_1 S_2 are arranged opposite to the telephone disc E E.

The induction coils and the magnet of the telephone are made use of here for signalling. The pole-shoes p_1 p_2 are scooped out semi-cylindrically, and metal plates M M_1 are fastened upon the arms of the horse-shoe magnet H H, which carry two sets of wheel-work *r g h i*. The metal piece *m m* is fastened upon the axis *a* of the spur wheel *r*; *e e* are semi-cylindrical iron pieces, which, with the shoes, form an almost uninterrupted armature (p_1 *e* p_2), which connects the poles of the horse-shoe magnet H H. This arrangement excludes, so to say, the iron cores of the coils s_1 and s_2, and thus considerably weakens their magnetism. But when the metal piece *m m* is turned about its axis *a* through 90°, the iron pieces *e* e_1 stand at the ends of the horizontal diameter, the armature p_1 *e* p_2 is interrupted, and the magnetism of the iron cores in the coils s_1 s_2 therefore attains to its original strength. If the metal piece *m m* be now made to rotate quickly by means of the handle K, the magnet will be opened and closed in quick succession; twice for every full revolution, as arranged in the drawing. The result of this change is that powerful currents are induced in s_1 and s_2. These induced currents reach the telephone at the distant station, making the membrane vibrate audibly. A further increase of tone may be obtained in different ways. Münch, for instance, transmits the vibrations to a bell. For this purpose a small box is placed in the mouthpiece B B, having the rod *t* resting upon the membrane E E, while the ball *b* is fastened upon *t*, and is also connected with this box in such a way that its position can be regulated by the screw *f*. When the membrane begins to vibrate, the motion of the ball up and down causes the bell *d* to ring.

Telephone Stations.—Returning now to this subject, we shall first consider stations where magneto-electric telephones are used exclusively. Care has to be taken that the several parts of the apparatus are well arranged, and protected from dust, etc. As an example of such an installation, we will first describe a German telephone office, as it is described in Grahwinkel's *Lehrbuch der Telephonie*. Fig. 693 gives an outside view of the whole apparatus; Fig. 694, the inside of box K. There are to be seen from outside the receiver T, which hangs on the hook *h*; the mouthpiece M of the sender S; the little box E, which contains the electro-magnet of the call apparatus; the bell *g*, with its hammer, and the key *t*. The remaining portions of the apparatus are enclosed in the box K, which contains, besides the sender S, the contact lever, the contact arrangement belonging to the key, and a lightning-protecting apparatus. The contact arrangement for the alarm consists of the wooden board B, to which are fastened the three brass pieces m_1 m_2 and m_3; m_3 is attached to the metal strip F, which has at its upper end the cylindrical piece *t'* horizontally arranged, and reaching through the side of the box as key *t*. By pressing upon *t* the cylinder *t'* is pushed against the contact-plate fastened in *b*, and the current of a battery consisting of from five to six Leclanché elements is sent through the line to the signalling apparatus of the distant station. The contact-lever *c c*, one end of which reaches a hook *h* through the side of the box, moves about the axis *o*; the other end of this lever has two contacts, opposite to which are the contact-

piece p_1 on the one side, and the contact-screw p on the other. The spiral spring f tends to draw the inner end of the lever downward, *i.e.* tends to make contact at p_1. As long as the telephone T hangs on this hook, the contact at p is closed by the lever $c\,c$; but when T is removed from the hook, the spring f draws the lever downward, making contact at p_1, whereby the bell is taken out of the circuit, and connection made between the two telephone stations.

The apparatus for protection against lightning is intended not only to protect the apparatus and locality against currents of atmospheric electricity,

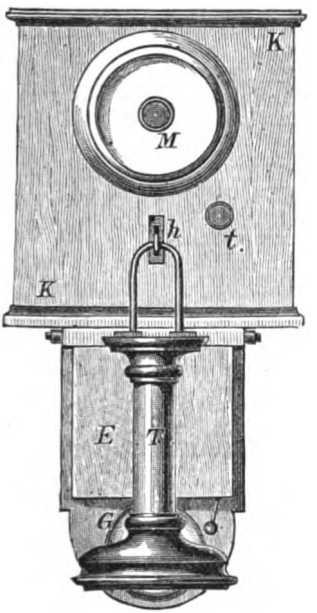


Fig. 693.

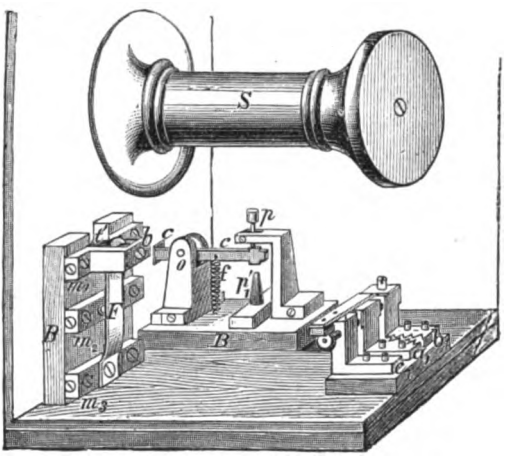


Fig. 694.

German Speaking and Receiving Instruments.

but also persons operating or standing near the instrument. The construction of the lightning conductor is shown in detail in Fig. 695. The spindle consists of a brass cylinder M. One end of it is screwed into the ebonite piece e, the other end is connected with the ebonite piece e_1 by means of a screw; m_1 and m_2 are brass cylinders, forming the end portions of the spindle, which consists of three brass cylinders m_1 M and m_2 insulated from each other. Copper wire of 0·1 millimetre carefully covered with silk is wound round the portions $m\,m$. The wire ends of the coils are led through the grooves n, and connect the coils with each other as well as with the two brass cylinders m_1 and m_2 by means of the binding screws s_1 and s_2. The middle portions of the spindle, being covered with wire $d\,d$, do not touch the sides of the hollow space $h\,h$ of the brass piece a_1. Care is taken that the contact shall be good between

the brass pieces b_1 a_1 and c_1, and the brass cylinders m_1 M and m_2. This is brought about by the springs $f f_1 f_2$ fastened to the screws r r_1 r_2.

The battery currents reach the lightning conductor through b_1, passing through the brass cylinder m_1, then through *s n d n d n s*, into the brass piece c_1 and then to the apparatus (compare Fig. 694). If a current of high potential reaches the leads towards b_1 during a thunderstorm, for instance, the main portion, instead of flowing through the thin wires *d d*, will cross the teeth of b_1 and a_1 (Fig. 694), and then flow to the earth. If the branch current entering at *d d* is still sufficiently powerful, it will destroy the thin wire of the coil, or at all events its silk insulation, making contact with the piece a_1 leading

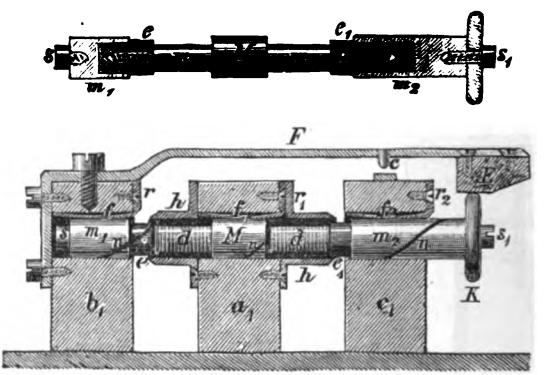


Fig. 695.—Spindle Lightning Protector.

to earth. When such an apparatus has been destroyed, the spindle is taken out from the pieces b_1 a_1 c_1, and replaced by a new one. In order that the line may not be broken during these manipulations, a strong brass spring F, which has a contact at c, is screwed to b_1. As long as the spring F is in its place, it presses with its ebonite block E against the knob K of the spindle, and prevents c and c_1 from touching. If the spindle is taken out the spring F presses the contact-pin down, and connects b_1 and c_1. The efficiency of this contrivance is shown by the following fact: An unusually heavy thunderstorm passed over Leipzig on the 19th May, 1884, at which time there were 285 offices established; although only two electro-magnets were damaged, forty-one spindles had to be renewed. A piece of an insulator was broken off, and the wires belonging to it were also torn. The total quantity of electricity which went down a post upon the roof of a house flowed in three different ways to the earth without causing any further damage.

Böttcher's installation of a telephone station with apparatus, specially adapted for the use of mines, is shown in Fig. 696. Iron is used in the construction instead of brass wherever this is possible, in order to prevent

oxidation. The frames of the receivers, of which there are two at every station, are made of tinned sheet iron instead of wood. The induction coils are soaked in paraffin, and together with a magnet-inductor, which is used instead of a battery, are enclosed in a box consisting of tinned sheet iron. The bell apparatus is not connected, but may be placed in position when desired.

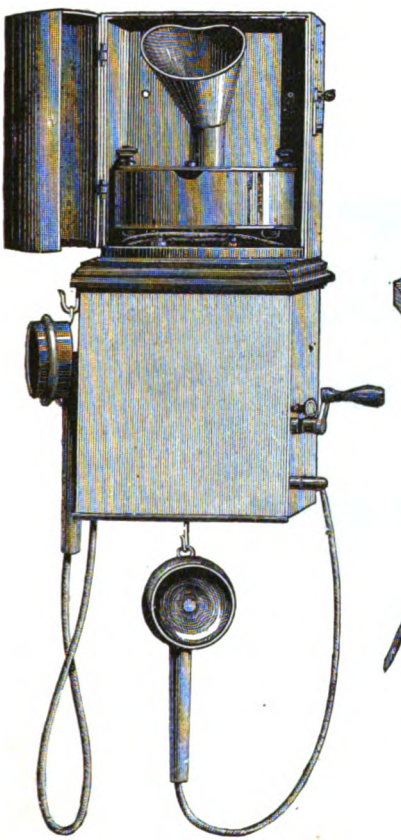


Fig. 696.—Böttcher's Telephone Station.

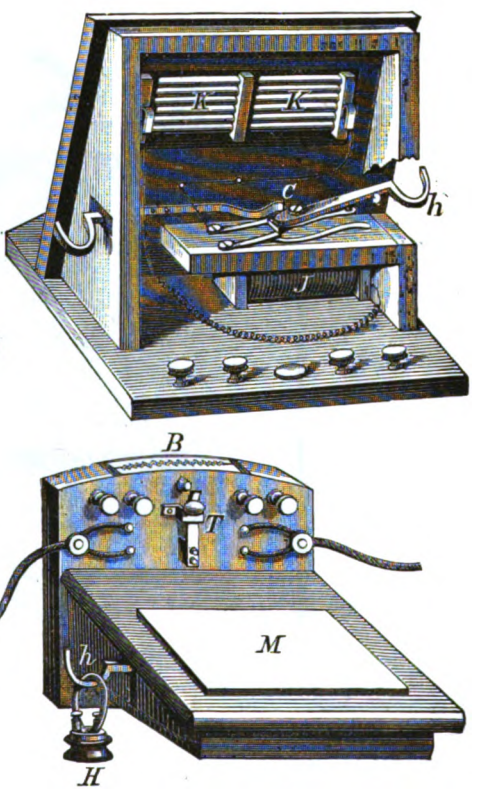


Fig. 697.—Ader's Telephone Station.

Ader's station installation is shown in Fig. 697. The several instruments are either enclosed in a desk-shaped box or fastened to it. The lightning-conducting apparatus B is arranged outside. The key T, by means of which the bell at the next station may be rung; the receiving telephone, which hangs on the hook *h* of the contact-lever, and the membrane M, are also placed outside this box. An Ader's microphone is placed inside, which consists of twelve carbon rods K, forming twenty-four contacts with the carbon prisms,

which are arranged cross-wise. The induction coil is placed at J, and the contact-lever C is fastened upon a board which is arranged over K. The bell is placed separate from the apparatus, and a battery is used to work it.

Fig. 698 shows an arrangement by De Locht-Labye. A thin cork plate P is placed in the little box to the left. To the lower portion of it is fastened the carbon disc K, against which the contact-pin leans. To the right is placed the electro-magnet W of the alarm, the bell of which, G, is placed outside the box; the disc S is connected with the electro-magnet, and thus an optical

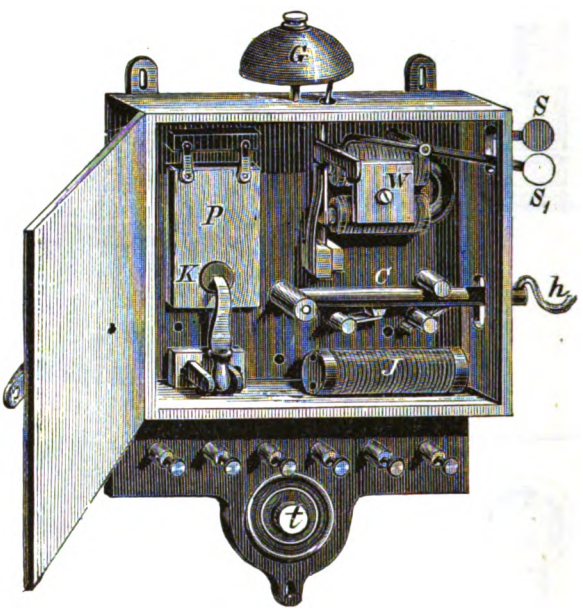


Fig. 698.—De Locht-Labye's Telephone Station.

signal is given at the same time as the bell signal. The receiver, as before, is placed on the hook *h* fastened to the contact-lever C. J is the induction coil, and *t* the key for making contact with the bell battery.

We have only at present considered the arrangements for a simple station; we will next consider the arrangements for central stations. The wires of all the subscribers must terminate at the central station, because each of the subscribers must be able to communicate with the central office, and also with every other subscriber. For this purpose a commutator must be placed at the central station, by means of which the above conditions are fulfilled. This instrument then must consist of an apparatus by means of which every subscriber can indicate that he desires to speak, and further, of an apparatus that enables the different subscribers to communicate with each other. Instru-

ments of various forms and constructions are in use, but in principle can be divided into two main types, viz. the Schweizer apparatus and the Jack-knife apparatus.

The principle of the Schweizer apparatus may be seen in Fig. 699. Upon a ground frame, usually in the form of a desk, are fastened the metal bars *a b c d* . . . T and E; the well-insulated bars 1 2 3 4 are arranged over these. The bars *a b c d* are called horizontal bars or plates; the bars 1 2 3 . . . are called vertical bars. T is termed the telephone-bar, and E the earth-bar, because T is connected with the speaking apparatus of the central office, and E with the earth-wires. The wires of the subscribers terminate on the vertical bars at I, 2, 3 . . . having first passed the indicators i_1 . . . i_4. The horizontal bars, when at rest, are single insulated metal strips. The bars may all be connected with each other at their crossings by means of metal plugs. The mode of action of this apparatus is as follows: If none of the subscribers wishes to communicate with another, all the plugs will be inserted in the bars (as seen in the figure III), *i.e.* the wires of all the subscribers go through their respective indicators, and then through the vertical bars to the earth-bar E, and so to earth. When one subscriber wishes to communicate with another, he signals with the help of the apparatus to the central station. The slide of this subscriber now falls down at the central station, and allows his number to appear. The officer, seeing that a subscriber (for instance, No. 4) wants to speak, takes the plug out of E and places it at IV. Bar 4 is now connected with the telephone bar, and the subscriber can be questioned about his wishes. Suppose now that it is made known at the central office that A_1 wishes to speak with A_2. The plug of A_1 is taken out of the E bar and placed at I, also the plug at A_2 is taken out of the E bar and placed at II, and in this manner the wires of two subscribers will be connected. Although it does not matter which horizontal bar is chosen, care has to be taken that both plugs are placed in the same horizontal bar without leaving their vertical bars, and that only

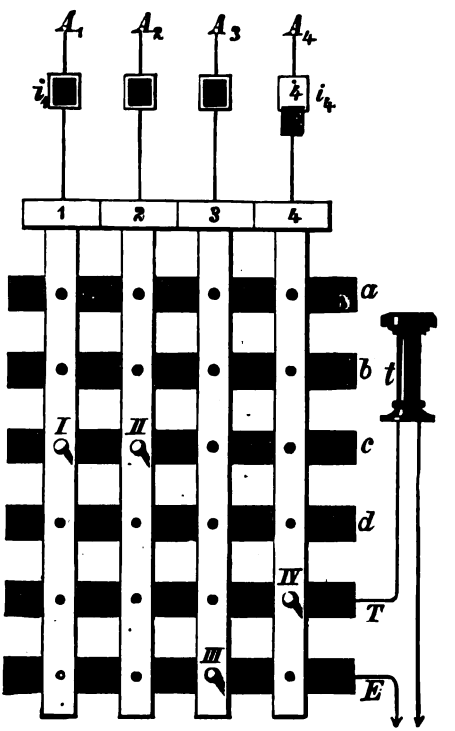


Fig. 699.—Schweizer's Telephone Commutator.

such horizontal bars are chosen as are not in use already. If, for instance, A_1 is connected with A_2 by having their plugs inserted at I and II, the horizontal bar *c* can no longer be used for connecting A_3 with A_4; either *a*, *b*, or *d* must be chosen.

An instrument constructed on the principle of the Schweizer apparatus by J. Berliner, of Hanover, for twenty-five subscribers, is shown in Fig. 700. The

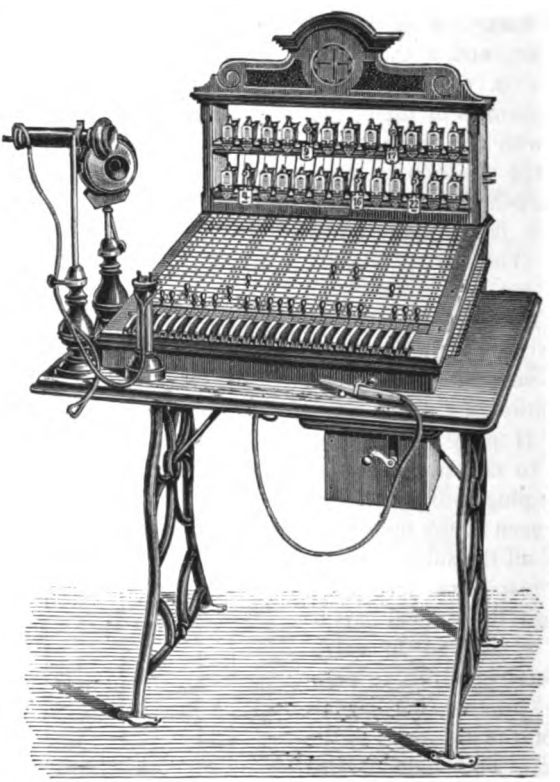


Fig. 700.—Berliner's Central Commutator.

commutator is arranged upon a desk-shaped frame placed on the table, and the indicators are arranged in a vertical box placed behind the table. Berliner arranges the horizontal bars above the vertical bars. On the table lies a double plug, by means of which either the call or speaking apparatus of the station may be connected with that of any one who wishes to communicate. To the left of the table are placed the sending and receiving apparatus of the central station. Underneath the table is a box containing the inductor for the bell apparatus, for which a battery may be substituted. In

the figure it is assumed that 4 is communicating with 8, 9 with 22, and 16 with 17. The plugs of the remaining subscribers remain in the lowest horizontal bar.

The Jack-knife Apparatus, devised by Wilson and Haskins, is shown in Fig. 701; but the indicator is left out of the figure. The name is derived from the fact that the connections are made by means of plugs resembling the handle of a "jack-knife." The wire, indicated by "Line," connects the subscriber with the central station. The key h_1, which moves about a, rests upon h_2, which is connected with the earth; and the subscriber can signal to the central station by pushing in the plug. This plug, or jack-knife, has an insulating handle S, with a collar $r\,r$, through which the line-wire l passes to a metal contact-point $b\,s$. The collar of the plug fits into a metal socket $m\,m$, and, when pushed in, the point raises h_1 from h_2, so breaking contact with each, and making contact for the subscriber. The jack-knife apparatus is placed at the central office, with the indicators of all the subscribers arranged in a case, as shown in Fig. 702. The lower portion of these cases contain shelves, which serve to hold the batteries B, of Leclanché elements. The upper part of the case G G is divided into five portions by the iron bars n, screwed upon the wood; each of the five portions is divided by ten partitions, so that the whole case has fifty cells or pigeon-holes, each of which contains an electro-magnet. The inside of these partitions is shown in Fig. 703. The space between two adjacent iron bars n is occupied by the iron plates p. These iron plates have painted on them the consecutive numbers, commencing with 1 to the left at the top of the case, and finishing with 50 to the right at the bottom. These numbers are, however, hidden by the covers K when the subscribers are not speaking, but the covers fall down against the pins i when the central station is communicated with. Underneath each series of covers, holes are arranged which are covered with brass; these have the same numbers as the covers above them, as shown in the figure (Fig. 703). There are other and similar holes also arranged along the sides in the vertical bars, each bar having twenty-five. The even numbers are on one side, and the uneven numbers on

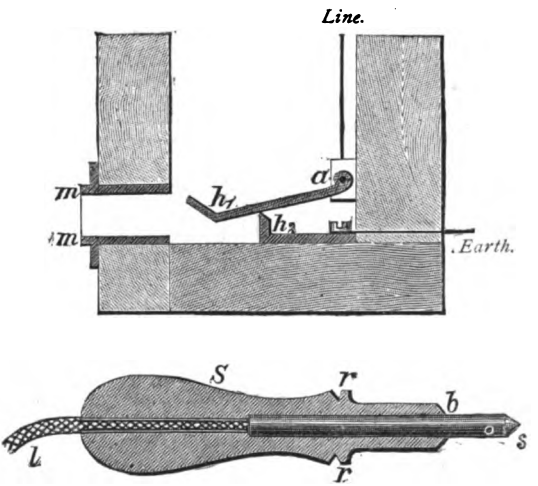


Fig. 701.—The Jack-Knife Connection.

the other. We shall explain the reason for this arrangement further on. Inside the cell is the horizontal ground-plate *g*, fastened to the lower end of plate *p*; upon this ground-plate and the wooden bar v, rests the electro-

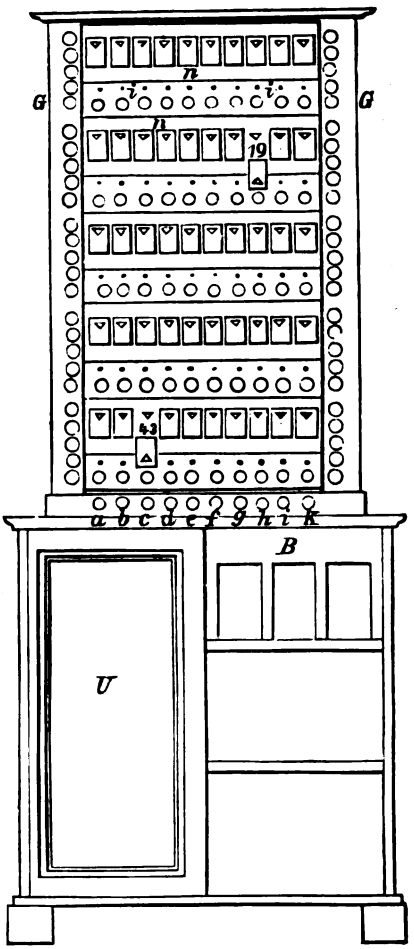


Fig. 702.—Jack-Knife Apparatus of Central Station.

magnet, of which only the arm E is covered with wire, whilst the core E_1 is left without any coils. The latter carries the brass piece w, to which the spring *f*, with the armature *a* of the electro-magnet, is fastened. The position of the armature can be regulated by means of the screw R. The end of the armature has the hook h_1 fastened to it, which projects through an opening of the plate *p*. The cover K movable about *c* which covers the number on the

plate *p*, has fallen down and rests upon the pin *i*. The cover has also an opening through which the hook *h* passes, and thus it is kept closed when no current flows through the coils of the electro-magnet. The ends of the latter terminate in the insulated brass plate *m*; one end is connected with the wire of the subscriber, and the other with the earth. Whenever a current passes through the coils of the electro-magnet, E attracts its armature *a*, and lowers the hook *h*. The cover K now falls upon the pin *i*, partly by its own weight and partly by the pressure which the small spring *b* exercises, and allows the number upon the

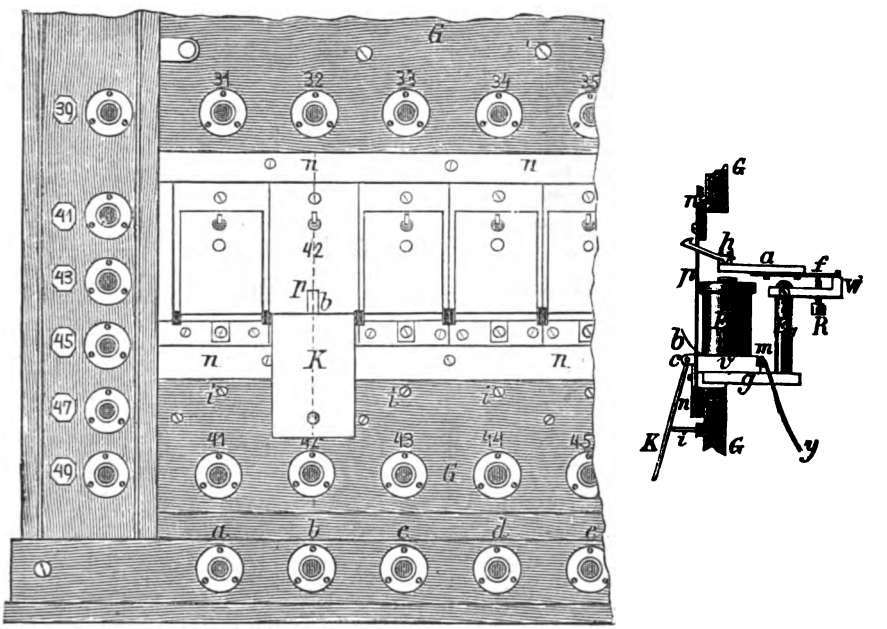


Fig. 703.—Cells of the Apparatus.

plate *p* to be seen; upon this the clerk at the central office connects his apparatus with that of the subscriber. We may here mention that in Germany subscribers use telephones both for senders and receivers; microphones, by Blacke or Berliner, are only used at the central stations.

We have now to consider the arrangement of the twenty-five holes in the vertical bars at both sides of the case. If the plugs were placed in the holes under the covers of the subscribers that wish to correspond, the indicators of both would be inserted, and the resistance in the leads uselessly increased. To prevent this, boxes are arranged at the sides of the case, corresponding to those in the middle of the frame, but differing from them by having no indicators behind them, but only jack-knives. Hence for the connection of any two

subscribers two kinds of plugs can be used, viz. one by means of which the indicator is inserted, and another which involves no such result; one of the indicators can, therefore, be left out when two subscribers are connected. Suppose A wishes to speak with B. For this purpose A presses the key *t* of his apparatus in Fig. 704, causing the current of his battery, B, to take the follow-

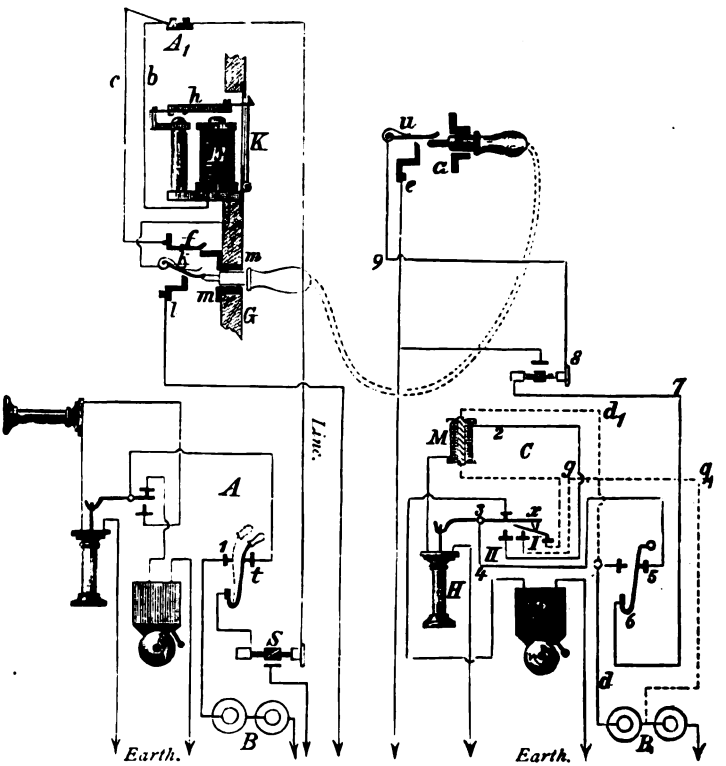


Fig. 704.—Diagram of the Telephone System.

ing course to the central office: through the wires to clamp A_1, which is fastened to the upper edge of the case at the central station; two ways are now open to it, viz. over *b*, round the electro-magnet E, through K, to the contact *l*, and then to the earth; or over *c*, through the spring *f*, and the metal rim of the bore *m m*; but as the metal rim is insulated in the wooden bar G, and the current cannot flow any further when the plug is not inserted, the current therefore takes the first direction, that is over E, consequently the electro-magnet attracts its armature *h*, and causes the cover K to fall down, and to expose the number of the subscriber A, who wishes to speak. The person at the central office now places one of the plugs in the hole *m m* under K (shown by dotted lines in the

figure), and the other plug in the hole *a*, as in Figs. 704 and 705. The latch *k* is lifted from *l* and brought into contact with the pin of one of the plugs, whilst the pin of the plug in *a* lifts the latch *u* from the earth-wire *e*, and thus joins the apparatus of the subscriber A with the apparatus C of the central station. The clerk can now communicate with the subscriber as soon as the receiver H has been taken from the lever. When a microphone is used the latter has, as already mentioned, to close two contacts I and II, because two currents are produced, the one primary and the other secondary. For this purpose both contacts I and II are arranged underneath the lever, and a metal spring is pressed

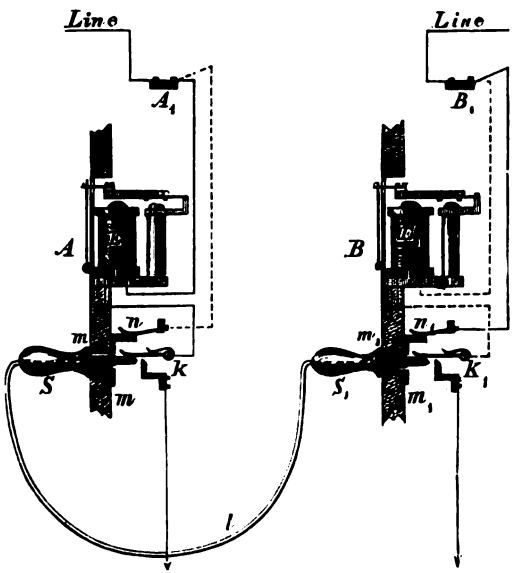


Fig. 705.—Mode of Communicating through the Central Station.

upon contact I by turning the lever. The metal spring is connected with the primary wire in the microphone M, by means of the pin X. The other end of the primary wire is connected with the battery B_1. When the lever presses down the spring at X the primary current of the battery B_1 flows from B_1 over $d\,d_1$ into the primary coil of M, then through the metal spring to the contact I, and so through *g g*, back to the battery. The secondary currents flow from the secondary coil over 2, contact II, the lever 3 5 6 7 8 and 9, to *u*, which is connected with the apparatus of A. The connection of the subscribers A and B, at the central station, is shown in Fig. 705. A_1 and B_1 are the clamps which join their leads. If two insulated plugs S S_1, of a construction like that shown in Fig. 701, had been taken, the electro-magnets E E_1 of both subscribers would have been inserted. To avoid this, only one of the plugs S is of the ordinary insulated construction, while S_1 is surrounded by a metal cylinder at the collar

m m, connected with the point, and so connecting the line-wire with the shunt-contact n_1. In this case the current between A_1 and B_1 is as follows: From A_1 over the electro-magnet E to latch K, and then through the contact-pin of plug s to plug S_1. No current can pass from A_1 through the dotted leads to *n*, because the pin of plug s is only in contact with K. From S_1 two ways are open to the current, viz. through the contact-pin of the plug S_1 over latch K_1, and the electro-magnet E_1 to B_1; and secondly, from the metal fastening of this plug over *m n*, to B_1. On the first road the current has to overcome the resistance of the coils of E_1, on the second road hardly any resistance is to be overcome; the current, therefore, takes the road described last, the consequence being that the electro-magnet E_1 is taken out of circuit whilst E remains in it. When A and B have finished their conversation, A again sends a signal to the central station. The officer at the central station takes out both plugs, and establishes the conditions that existed at first. Instruments like those described are constructed by various firms of electrical engineers, with slight modifications in details, the general principle being the same in all.

The "Leads" or Connections of a Telephone System.—In order to obtain a complete picture of the fittings and mode of action of a central station, we shall now have to consider the leads which connect the several stations with the central stations. It is of the utmost importance that the leads should be carefully constructed and well arranged, as the system will not otherwise work in a satisfactory manner. If the main lines are badly arranged, the difficulties of connections will be greatly increased. The main points which ought to be observed when drawing up a plan are as follows: The lines ought to run radially from the central station, and thus facilitate connection with the various houses. The installation ought to be such as to allow of a considerable increase in the extent of the system on all sides; for this purpose main lines should be constructed with treble and multiple poles, because simple poles do not permit any considerable increase of their weight. The crossing of wires must be carefully avoided, because if a wire should break considerable expense and disturbance would be caused by the broken wire falling across others passing longitudinally beneath them. If several telephone offices are erected in the same town, each one ought to have its own district. The supports for leads which are overhead ought to be chosen, placed, or constructed with quite as much care; if roofs are used for this purpose it is necessary to carefully examine their structure. Most people have a strong objection to allow their roofs to be used for these and similar purposes, believing that by doing so the danger of lightning is increased. The opinion is still frequently entertained that the office of a lightning conductor is to draw down the lightning and convey it to the earth, and that the iron matter, without being connected to the earth, would become dangerous. This idea, of course, is entirely erroneous; in reality the effect of a lightning conductor depends upon the point. A positive electric thunder-cloud, for instance, generates negatively induced electricity in the building over which it may pass. If the tension is sufficiently great, exchange

or the two electricities takes place in the form of an electric spark, and thus produces what is called lightning. If the building has a metal point, or a lightning conductor, the negatively induced electricity will flow through it to-

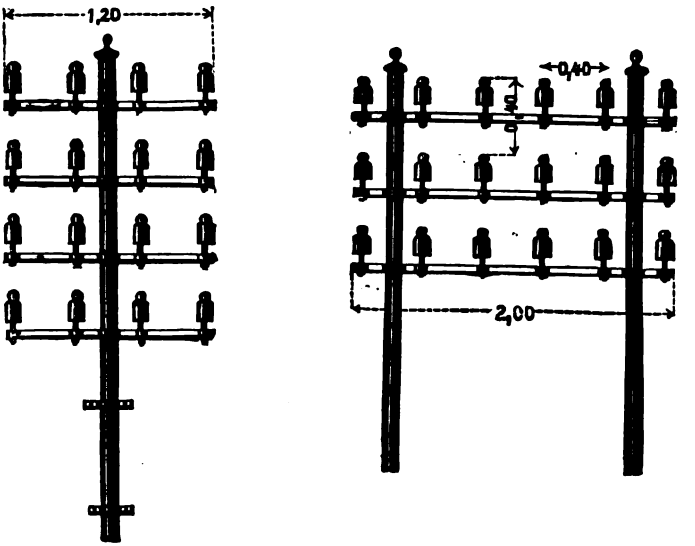


Fig. 706.—Supports for Telephone Leads.

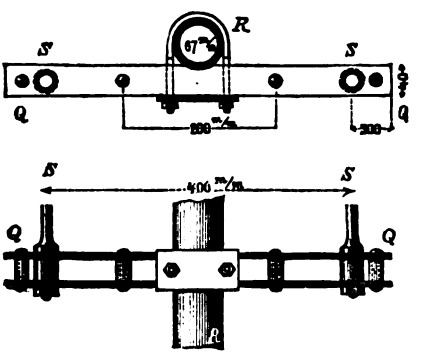


Fig. 707.—Supports for Telephone Leads.

wards the cloud ; whilst the positive electricity will flow along the metal down to the earth.

The Wires and their Supports.—The wires generally in use consist of either iron or phosphor-bronze. The posts consist either of iron or wood. The former are composed of wrought-iron tubes of from 6·7 to 7·5 centimetres in outer diameter, and 0·5 centimetre in thickness; arrangements with one and two tubular posts are shown in Fig. 706. The mode of fastening the

cross-bars Q Q, and the supports s s for the insulators, is shown in Fig. 707. The ordinary insulator supports are usually straight, as shown in Fig. 707, s s; but if the wire branches off, almost vertically U-shaped insulators have to be used, as shown in Fig. 708; moreover, the contact of the wire with the iron posts is more easily avoided by this arrangement. Wood-work is preferable to brick-work

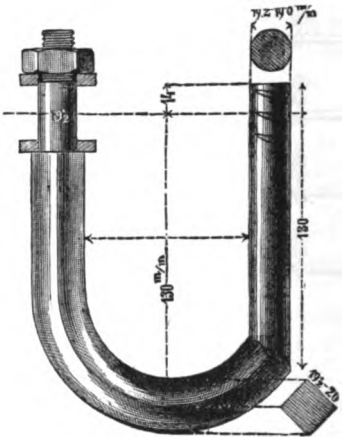


Fig. 708.—Insulator.

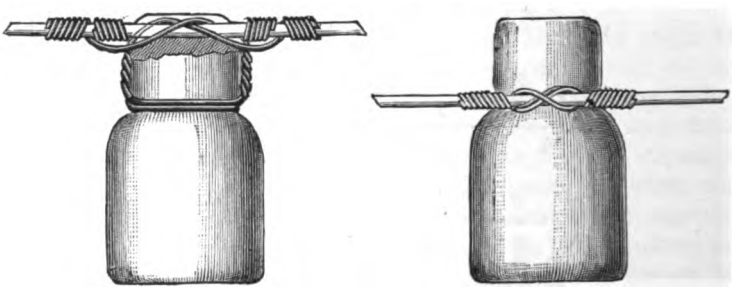


Fig. 709.—Top-tie and Side-tie Insulators.

for the fixing of iron posts, because in the latter the humming of the wires is far more pronounced. Care ought to be taken, however, that everything is firmly and securely fixed. The wires are fastened to the insulators in the following way: At each post is placed a man with a line, and the men at the first and last posts have light wooden drums, on which the wire is coiled. Each man throws one end of his line in the direction in which the leads are to be arranged; every two ends are then connected by men placed in the right position for this purpose. This is continued until a continuous line is produced. The wire at the first post is now fastened to the line and drawn over all the different posts. When the first wire has been fastened to the last pole, a second wire is fastened to the line,

and drawn by the second line to the first post, and so on. The fastening of the wire to the insulators is shown in Fig. 709; zincked iron wire of 2 millimetres diameter is generally used for the purpose. The so-called top-tie is used for straight lines; side-tie for angular lines. The humming of the wires is often very objectionable; it is caused either by the vibrations of the wires through the wind, or by molecular vibrations, which arise through change of temperature, or perhaps, as Zacharias thinks, by the vibrations of the insulators and wires. Different means have been adopted to prevent the conduction of this humming to the instruments: the tubular posts sometimes, for instance, are not fastened directly to the ground frame, but a layer of lead, 8 centimetres thick, is placed between. The posts themselves are filled with ashes, sand, or

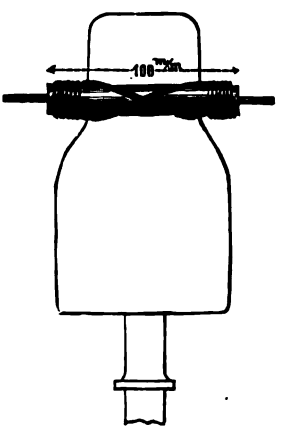


Fig. 710.—Contrivance to Prevent Humming.

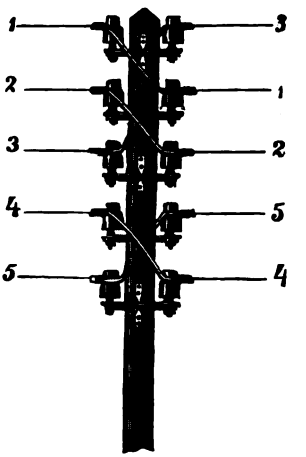


Fig. 711.—Contrivance to Prevent Induction.

similar substances, and are, as we have already said, fastened to wood-work instead of brick-work. The German Post-office Department has introduced a manner of fastening the wires, which is shown in Fig. 710. An india-rubber tube, the bore of which just fits the wire, is slit open and placed round that portion of the wire which is to be fastened at the pole; a length of about 10 centimetres is generally taken; the india-rubber tube, which faces with its slit to the insulator, is wound round with lead-tape, and the whole bound to the post with ordinary wire. According to Zacharias the humming is almost entirely avoided by winding doubly-covered and well-waxed copper or lead wire round the portions which touch the insulator. A sure, but rather expensive, cure is to have a chain fastened to the wire ends, and connected with the insulators by means of india-rubber.

Induction.—When two or three telephone wires run parallel to one another, great disturbance is often caused by induction, so that a man stationed at the end of one line can hear all that is said at another. A method of

obviating this is to make the conducting wires cross one another at every third or fourth post, as is shown in Fig. 711. For this purpose double insulator stages are employed, and the lines are made to end *at the insulators*, as in Fig. 711. The cross-wise connection is then established by isolated wires carried round the posts, as indicated in the figure.

It is difficult to decide whether separate lightning conductors ought to be constructed or not; house-owners, over whose roofs the leads run, are often anxious that lightning conductors should be erected; although probably the wires and earth connections are sufficient. Every fourth post is generally converted into a conductor by connecting it by means of a wire rope with the earth.

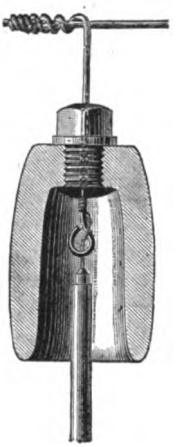


Fig. 712.—Connection of a Branch with the Main Lead.

The posts that are not connected with the earth should be connected with those posts that are, by means of wires 4 millimetres thick; and any metal matter, such as cisterns, etc., that happens to be near the building, ought always to be carefully connected with the posts. For the earth connections belonging to the lightning conductors, the Prussian engineering committee suggests that each lead should be provided with a plate, sunk under the lowest water-level; a well can be used for this purpose when it lies outside the building. When no water can be reached, the leads should branch off every 5 metres in veins 3 metres long; earth-plates are not necessary when this is done. Where plates are necessary, copper plates 2 millimetres thick, and having an area of 0·25 square metre in water, and an area of 0·5 square metre in damp earth, are generally employed. When several plates are required for the same building the dimensions may be smaller. The leads to the different subscribers branch off from the main leads, and are conveyed along insulators, which are fastened to the brick-work of the building; in this manner the leads are conveyed as near as possible to the room where the apparatus is placed. A hole is made in the wall underneath the insulator where the lead ends, through which the tube cable, which connects the outer leads with those inside, is passed.

The joints of branches or stations are protected by means of a gutta-percha cover, shown in Fig. 712. Iron wire coated with zinc is let in at the top of the cover, which is perfectly watertight, is wound round the leads in the manner shown in the figure, and then soldered; the end reaching inside terminates in a loop, and the bright copper wire of the cable is connected with the loop. The cover has to stand vertical, and must not touch the cable tube with its edges. The inside lead consists of copper wire 1 millimetre thick, which is covered with cotton, and then soaked in wax. The earth lead consists of copper wire of 1·5 millimetre diameter, which is usually soldered to the gas or water pipes; where this is not possible three wires of 4 millimetres diameter are twisted together, and this cable is connected with the

ground-water. Fig. 713 shows the way in which the wires are collected at a central station. A wooden tower is erected on the roof of the building, and the insulators are arranged in rows along the outside. The tower is covered with a projecting sheet-metal roof. It has also a door and a platform, which is railed in. Inside the tower the leads are conveyed by cables composed of four tubes, which contain the wires, and which are fastened to the walls of the

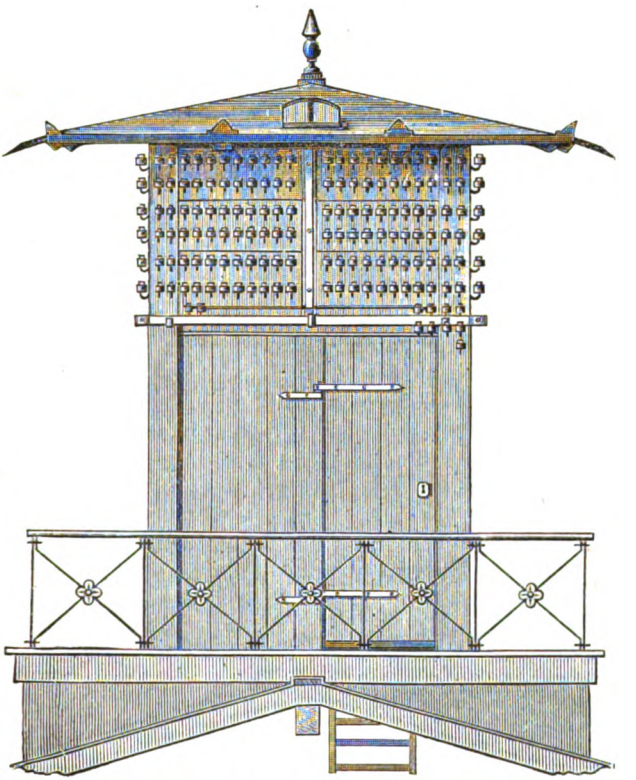


Fig. 713.—The Collector at the Central Station.

tower. The cables are free from the tubes at the upper ends, so that the insulated copper wires may be conveyed through the wooden walls singly, and then be connected with the line-wires on the insulators outside the tower. A wooden shaft reaches from the tower to the central station, through which the wires are conveyed to the different cases.

The Telephone System of Paris.—Whilst in most towns the leads used are overhead wires, those in Paris are almost all underground cables. Paris has the advantage of an extensive sewer canal system, and the telephone company was allowed to convey its cables through the different canal

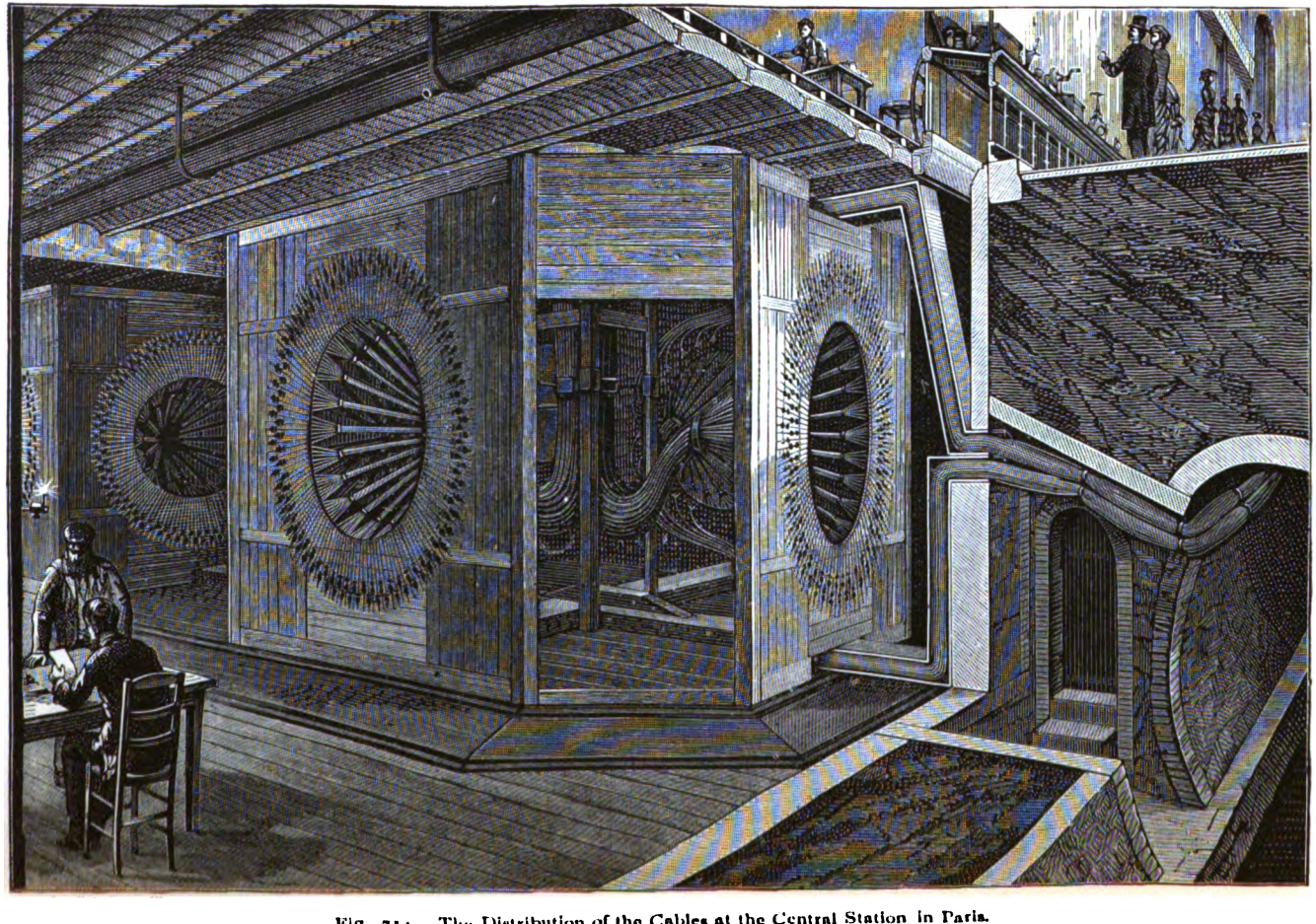


Fig. 714.—The Distribution of the Cables at the Central Station in Paris.

tunnels. The cables are fastened by means of iron hooks to the brick-work of the tunnel. Each cable consists of seven double leads (to and fro); that is, of fourteen single conducting wires. Each lead consists of copper wires 0·5 millimetre thick, insulated by gutta-percha from other wires. A cable formed in this manner has a diameter of 2·2 millimetres, inclusive of its gutta-percha cover. Each wire is covered with cotton of a certain colour, so that the two wires (the direct and the return wires) of one subscriber show the same colour. Seven of such double wires of different colours have tape wound round them, and are then drawn through the tube. A tube cable, containing seven double leads, including the tube and covering, has a diameter of 18 millimetres, whilst a cable with only one double lead (for the connection with only one

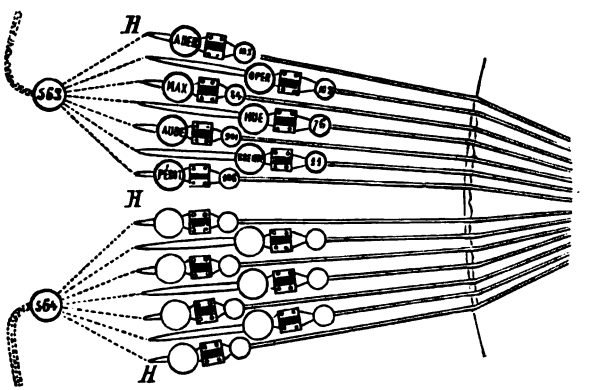


Fig. 715.—The Distribution of the Leads at the Central Station.

subscriber) is 8 millimetres thick. The introduction of the leads into the house of a subscriber is very simple. The cable containing the double leads is introduced through the basement, and is then conveyed along one of the walls to the apparatus. Fig. 714 represents the basement of the central station in the Avenue de l'Opéra, where the cables terminate. The door seen in the drawing leads to the entrance of the tunnel. In the basement are arranged eight-sided boxes of wood, the four large faces of which each contain an apparatus for distributing the wires, called, from their appearance, the "roses;" the small faces of the boxes have doors. In the figure one of these doors is left open to make the inside of the box visible. The cables are introduced into these wooden chambers, opened, and separated. The several double wires form large circles with their ends on the outside walls of the chamber, shown in Fig. 714, or in detail in Fig. 715. By referring to the latter we find that every cable arriving at the inside of the wooden chamber has a number (563 and 564), and that its seven double wires pass through the side at H H. From here, that is from the periphery of the "roses," the double wires run radially towards the circular opening in the wall of the wooden chamber; they are then again united

to form cables, and are conducted in a vertical direction to the commutator at the lower part of the central office, shown in the Frontispiece to this volume. The round discs of the outer circles, Fig. 715, consist of bone or ivory, upon which the names of the subscribers are written: the smaller discs bear their numbers.

For very great distances the apparatus and arrangements described above are insufficient; but even when magneto-electric telephones are exclusively used, conversation can take place at a distance of from 40 to 45 kilometres, assuming that the apparatus is in proper condition. The distance may be considerably increased by combining the telephone with a microphone. Experiments made during the Munich Exhibition, in 1882, with Bell's telephones and Berliner's

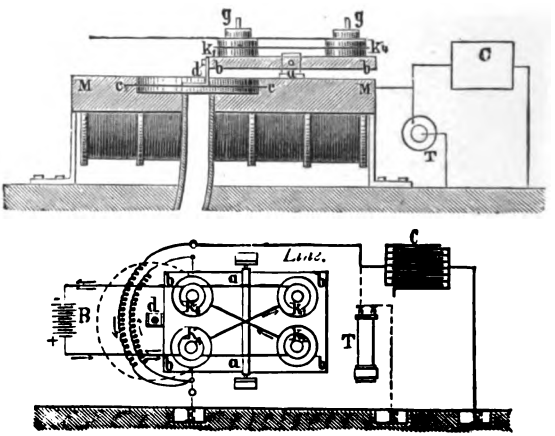


Fig. 716.—Herz's Microphone.

and Blake's microphones, showed that communication between Munich and Regensberg (a distance of 137 kilometres) was quite possible. Communication was also possible between Munich and Bayreuth (a distance of 282 kilometres): communication with Dresden, however (450 kilometres distant), was found impracticable.

Herz's System.—Very good results were obtained by Cornelius Herz, who increased the effect of the microphone by increasing the contacts, and putting them in a branch circuit of a powerful battery. He also prevented the induction due to neighbouring lines, by inserting a condenser in the telephone line, that is, by breaking the line at a certain point. Herz gave different forms to his apparatus, one of which we may describe here. The transmitter consists of the plate *b b*, Fig. 716, which moves about the axis *a a*, fastened to the ground-plate M M. The plate *b b* is connected with the membrane *c c* by means of the angular piece *d*, so that the vibrations of the membrane cause the plate *b b* to swing or oscillate. Four pairs of carbon discs k_1 k_2 k_3 k_4 are arranged upon *b b*. The upper four discs are kept in contact with the lower ones by means of leaden

weights *g g*. The upper discs to the left are connected on one side with the wires of the battery, and on the other with the upper carbon discs to the right, whilst the lower carbon discs are connected with each other by means of cross-wires. The direction of current in the transmitter—which is provided with an induction coil, and connected with the telephone T and the condenser C as receiver—is as follows: From the battery B the current reaches the upper carbon plate K_4, then flows through the primary spiral of the inductorium to the lower plate K_2, and then back through the upper plate K_4 to the battery.

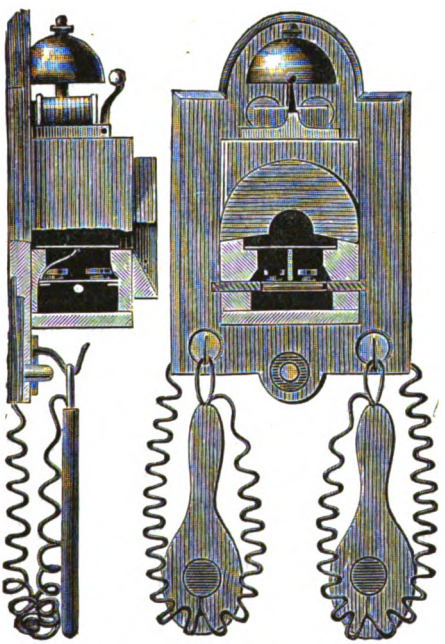


Fig. 717.—Herz's Telephone Station.

On account of the connection of the plates already mentioned, the current from the battery flows also into the upper plate K_4, then into the upper plate at K_2, from here to the lower plate K_3, and then back again to the battery; further, a current flows from the battery into the upper plate K_4 and then to the lower plate K_1, from here it flows to the upper plate K_3, and so back to the battery. These battery currents are converted into undulating currents when the membrane *c c* is spoken against, because the latter communicates its vibrations to the plate *b b*, causing alterations in the carbon contacts K_1 K_2 K_3 K_4. If, for instance, the membrane *c c* vibrates downward, *b b* with its left side will also move downward, whilst its right side will move upward. On account of the great rapidity of this vibration, we may assume that the

four upper carbon plates, with their weights *g*, remain stationary, because no time is allowed them to follow the motion of the lower plates. The motion downwards of the left side of *b b* will, therefore, diminish the pressure of the contact in K_3 and K_4, and increase the pressure of the contact between K_1 and K_2. The result of this will be that current impulses of opposite directions will be produced, which immediately follow each other. These impulses, being opposite, would produce neutral effects upon the secondary spiral of the inductorium if their directions were not made to agree by the cross-joining of the alternate carbon contacts. When this is done, the motion of the membrane downward, therefore, produces two impulses of the same nature, the one immediately succeeding the other, and an increase of microphonic effect is the result. The same, only in reversed order, holds good for the motion of the membrane upwards. The secondary coil is connected on one side with the earth, on the other side with the line. A magneto-electric telephone T may be used for the receiving apparatus, as well as a condenser C. The induced currents thus caused by neighbouring lines may be neutralised partly by the more powerful effect of the microphone, and partly in consequence of the interruption of the telephone line by a condenser.

The arrangement of a telephone station is shown in Fig. 717, but the induction coil is left out in the figure, as it is only inserted when comparatively weak batteries are used. Of the four carbon contacts only two are visible, because the other two are covered. Condensers are used for receivers, in wooden frames of a shape shown in the figure.

Herz with his system spoke between Orléans, Blois, Tours, Poitiers, Angoulême, and Bordeaux—distances of from 300 to 457 kilometres. During the night, when the neighbouring wires were at rest, he was even able to communicate between Tours and Brest, over Paris, a distance of 1,100 kilometres.

Connections.—It is of great advantage to connect the telephone offices of two different towns so that each subscriber of the one can communicate with each subscriber of the second. In this case, however, few wires could run parallel to each other for long distances on account of the disturbances which would be caused by induction. By using double lines to connect the telephone offices of the different towns, induction disturbances might be avoided; but the subscriber would also require a double lead for the connection of his apparatus with the office. This is not impossible, as was shown in the Paris installation, but it greatly increases the cost of the telephone network. Systems have therefore been invented which connect the subscribers' single leads to the double leads, and thus connect the central offices of different towns. Such systems have been devised by Bennett, Ryström, and Elsasser. Ryström's arrangement is shown in Fig. 718. The induction coils J_1 J_2 of the two offices to be connected are joined to the leads in the following manner: One end of the primary coil J_1 is joined to the earth leads, the second end to the single telephone leads of the subscriber. The ends of the secondary coil are connected with the line leads 1 3, and, with one coil of the induction apparatus at the second telephone office,

form a completely closed circuit. The second coil of the induction coil of this office is again connected on the one hand with the single telephone leads of the subscriber, and on the other with the earth. The undulation currents generated by speaking in the telephone station I produce induced undulating currents in the induction spiral J_1 of this station, which reach the induction coil J_2 of the distant office through the leads 1 3. When these currents arrive they induce undulating currents of a higher order, by means of which the words are reproduced in the telephone II of the subscriber. Although a double change of the undulation currents takes place by this arrangement, experiments made with leads 18 kilometres long, between Malmoe and Lund, gave satisfactory results.

In the arrangement devised by Elsasser, shown in Fig. 719, only one induction coil was used, together with a cable of four wires, connecting Cologne with

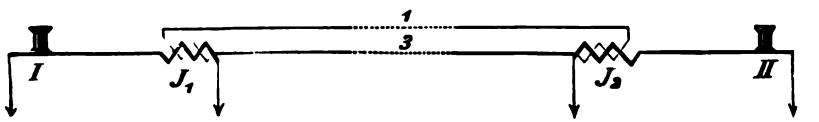


Fig. 718.—Ryström's Arrangement.

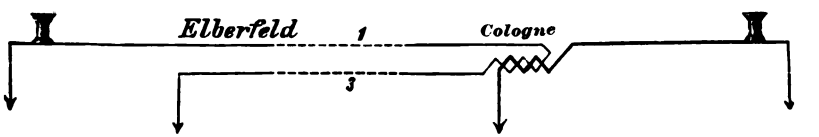


Fig. 719.—Elsasser's Arrangement.

Elberfeld. The telephone apparatus was connected on the one side with the earth, and the other with a cable wire 1 ; cable wire 3 was connected at Elberfeld with the earth. At Cologne the cable wires 1 and 3 were united by the primary coil of an induction coil. The secondary coil was connected on the one side with the earth, on the other side with a telephone apparatus by means of a single lead. This arrangement requires only a single change of the undulation currents (namely, in the induction coil at Cologne). The arrangement answered its purpose when the wires 1 and 3 of the cable were used—*i.e.* those wires that lie diametrically opposite to each other. When adjacent wires were taken (1 and 2, for instance) no satisfactory results were obtained. The above arrangements allow communications to pass between the two stations, but signalling through them can only be done by means of very powerful currents.

Fig. 720 represents a device by Elsasser, by means of which signals may be sent between the two stations. Besides the ordinary apparatus in the cover case at each station, an induction coil J, a relay R, and a battery B, are needed. The double leads end in the latches k_1 k_2 k_3 k_4; the contacts c_1 and c_3, belonging to these latches, are connected with the induction coils J_1 and J_2; c_2 and c_4 with the relay contacts v v are in contact with the earth. When at rest, the

jack-knife plugs U_1 and U_2 of a_1 and a_2 are in the holes belonging to the latches K_2 and K_4 (shown for plug U_2 in the figure). If the subscriber M of the office at town I wishes to speak with subscriber N of the office at town II, he at first sends a current to his office at I, which flows through the magnet s *m*, and then through the latch with its contact to earth, because plug U_1 is not as yet inserted. The armature s *m* of the magnet now falls down, and the attendant at the station I receives the signal of M. M will now be connected with the commutator apparatus and the double line 1 2 by the insertion of the plug U_1 into the latch belonging to s *m*. The office at II is now informed by signal, and inserts plugs

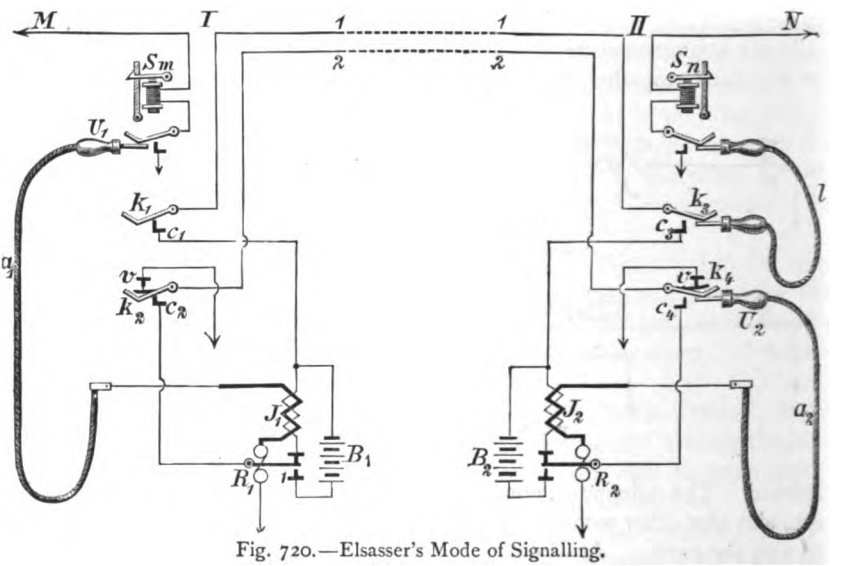


Fig. 720.—Elsasser's Mode of Signalling.

in the latch belonging to s *n* and the latch K_3. The current now sent by M flows through s *m* over U_1 a_1, through J J into the relay R_1, and then to earth. The relay closes the contact 1 of the signalling battery B_1, whose current now flows partly over 1, the line 2 2, latch 4, through the spring which touches contact v, to earth ; and partly from B_1 over C_1 K_1, through the line-leads 1 1 into the latch K_3, over s *n*, to subscriber N, whose bell it causes to ring. The undulation currents which are generated by the speaking of M take the following route : From M over s *m*, U_1, a_1, through the primary coil of J_1 to the electro-magnet R_1, and so, by means of the relay, to earth. The induced currents generated in the secondary coil of J_1 pass partly over the lever of the relay to C_2 K_2, through the line 2 2, K_4 and v, and then to earth, and partly over C_1 K_1, through the line 1 1 to the latch K_3, and the electro-magnet s *n*, and so into the receiving apparatus of subscriber N, and reaching the earth by that means. The undulating currents generated by the speaking of N take the same direction,

only reversed. Both N and M speak through the medium of the induction coil J_1; but signalling can only be effected by M, by the help of the more powerful current called into play by the relay. This is no disadvantage, however, for in German telephone offices the rule holds that the person who called shall also give the signal when the conversation is finished. If N wishes to speak with M the conditions are reversed—*i.e.* the induction coil J_2 only is used, and N alone can give the signal.

Precautions Necessary to Prevent Induction when the Same Line is used for Telegraph and Telephone.—According to Zetsche (*Elektrotechnische Zeitschrift*, vol. iii., p. 244) telegraph lines were used for telephonic messages for the first time in Dresden, in 1877, when a line belonging to Government was used both with a Morse apparatus and a telephone apparatus, and the experiments clearly proved that it was possible to use telegraph lines for the double purpose. Franz von Rysselberghe devised a method of using the same wire with a telegraph apparatus and a telephone apparatus, based on the application of so-called "graduated currents." The separation of the telegraph apparatus from the telephone apparatus is brought about by the insertion of condensers. We have already seen that the latter are capable of propagating telephonic impulses; while, at the same time, they interrupt the circuit of battery currents or induced currents—*i.e.* the currents used for telegraphing. When telegraphing in the usual manner, intermittent currents circulate in the circuit, the currents being made or broken suddenly. These momentary makings and breakings of the current cause powerful induction effects in the neighbouring wires, so that telephonic intercourse becomes impossible. These disturbing induction effects disappear, however, when make and break of current is gradual, and not sudden. The current increases gradually when it is made, and diminishes gradually when broken, so that by lengthening their duration the induced currents are weakened to such an extent that they do not interfere with telephonic correspondence. Much more time, however, would be required for sending telegraphic messages by means of graduated currents, and this is evidently the great disadvantage of the system. Rysselberghe converts ordinary currents into gradual currents in a variety of ways, either by inserting electro-magnets or condensers, or by using peculiarly constructed keys. If a battery current has to pass through the coils of an electro-magnet before it sets the telegraph apparatus in motion, it can only attain its full power gradually, because the electric current is employed for some little time in magnetising the iron core, and it is only when the latter is magnetised that the current will attain its full strength; inversely, on breaking the current its intensity cannot disappear suddenly, because magnetism does not cease all at once. A condenser, too, cannot attain its full charge or lose it immediately, when the current is made or broken. The key for the purpose of sending the current gradually has a carbon instead of a metal contact. The gradual change from strong pressure to total break causes a gradual increase and decrease of the current, just as it does in the microphone. The practical execution of these principles is

shown in Fig. 721. A is the telegraph office, B the telephone office, M represents the key, R a telegraph apparatus of any construction, P the battery, E_1 and E_2 electro-magnets. The former is inserted between P and M, the latter between M and the line L. C represents a condenser put in a branch circuit between the key M and the earth E, in order to connect the two electro-magnets, and C' represents a condenser that is connected on the one side with the telephone

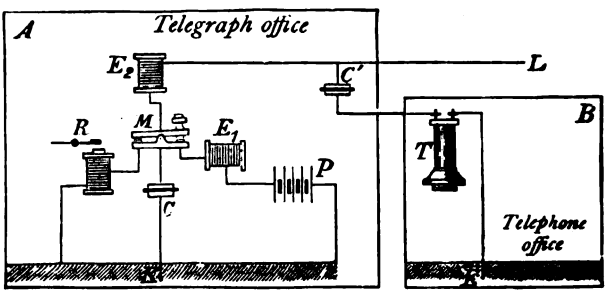


Fig. 721.— Rysselberghe's System.

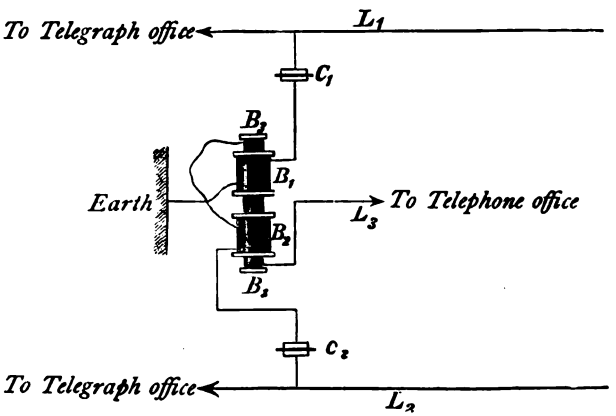


Fig. 722.—Rysselberghe's System.

station, on the other side with the telegraph line. The telegraph current coming or passing through the line L cannot reach the telephone T, because the line is separated from the leads of the telephone station by the condenser C': moreover the currents of the battery P, which are used for telegraphic messages, are converted into graduated currents by means of the magnets E_1 and E_2. The condenser, as already pointed out, offers no obstacle to the passing of the telephone currents through L.

The connection of two telegraph lines L_1 and L_2 to form one closed telephone line, as arranged by Rysselberghe, is shown in Fig. 722. C_1 and C_2 are

condensers; B_1 B_2 represent differential coils, which, by induction, affect the third coil B_3; one end of each of these coils is connected with the earth, whilst the remaining end of B_1 is connected with the telegraph line L_1, and the remaining end of B_2 is connected with the telegraph line L_2, and that of B_3 with the telephone line. The connection between L_1 and L_2 is broken for telegraph currents by inserting the condensers. The condensers, however, do not hinder the propagation of telephonic impulses. It will further be seen that the impulses passing through the coil B_3 must have opposite induction effects on the coils B_1 and B_2. They have the relation of + and − as regards each other, and consequently with L_1 L_2 they represent a closed telephonic line.

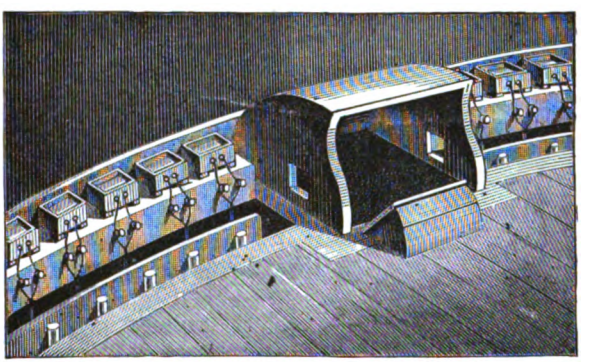


Fig. 723.—Ader's Music Transmitters.

Experiments were first made with this system in Brussels, in January, 1882; and owing to the favourable results which Rysselberghe has obtained with it, it is intended to utilise the whole of the telegraphic network of Belgium (29,122 kilometres of telegraph wires) for telephonic correspondence.

TELEPHONIC TRANSMISSION OF MUSIC.

The first public experiments were made at the Technical College, Vienna, by F. Nissl, and the author of the present work, in 1877. Bell's telephones were then used both as senders and receivers, but after the microphone had been perfected it was possible to operate on a much larger scale. During the Exhibition of Paris in 1881, the operas and the music of the Théâtre Français could be heard through the telephone in rooms which were specially adapted for the purpose, the installation being undertaken by Ader. The microphones were placed on both sides of the prompter's box in two series, as shown in Fig. 723. When arranging microphones for purposes like this, great care has to be taken (1) that the music of the orchestra and of the singing are equally well transmitted, so that neither the one nor the other is too loud; (2) that the

different positions of the singers do not interfere with the effect; and (3) that the microphone does not transmit noises caused by the walking of different people on the stage, etc. The shapes and positions which Ader gave to the mouthpieces of the microphones secured the equal reception of the instrumental music and the singing. To exclude noises the microphones were placed upon thick layers of lead, upon which pieces of gutta-percha had been fixed. The connection of microphone and telephone had moreover to be arranged so that the singers could be heard independently of their position on the stage.

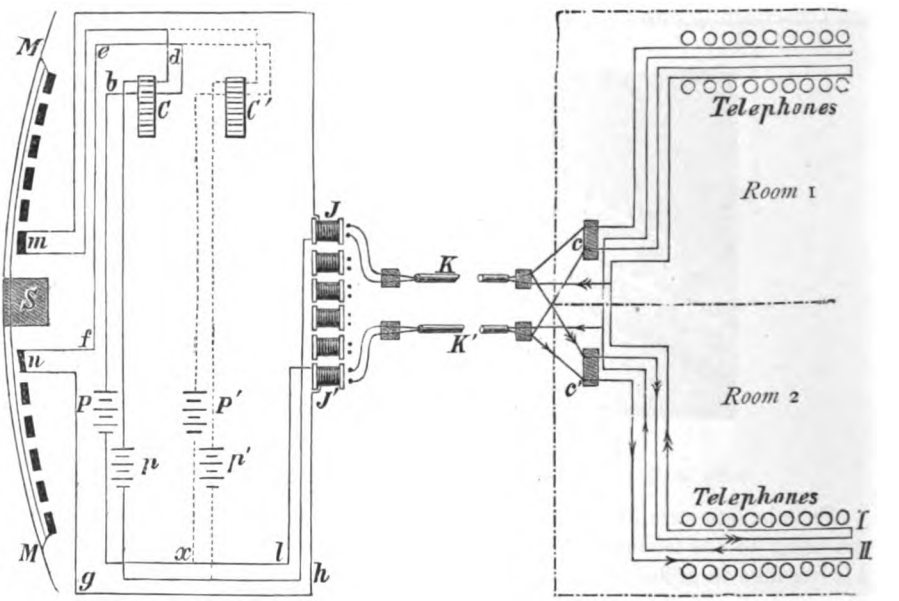


Fig. 724.—Ader's Arrangement of Music Transmitters.

The whole arrangement is shown in Fig. 724. According to Th. du Moncel, M M indicate the microphones arranged at both sides of the prompter's box S; P p and P' p' are batteries; C C' commutators, and J J' induction coils. The leads were conveyed from the opera-house through the cables K K' to the rooms in the Exhibition building (Palais de l'Industrie) where the receiving telephones were placed. c c' are commutators to connect one room, while the public were leaving the other and making room for a new batch of listeners. For the sake of distinctness, the whole direction of current is drawn for two microphones only. To each microphone belong three batteries (of which two only are drawn) and one induction coil. The batteries consisted of Leclanché's elements, which, as we know, do not remain constant very long; the elements had, therefore, to be charged frequently, which was effected by the arrangement of three batteries and a commutator be-

longing to each set. The direction of the current for the microphone *n* is as follows: From P over *b* through the commutator *c*, to *d e f* through the microphone *n*, over *g h* through the primary spiral of the induction coil J′ and over *l* back to the battery P. If P loses its constancy, P′ takes its place, and the direction of the current is as follows: From P′ through the commutator *c*′, then over *d e f n g h* J′ *l* to *x* and back to P′. The battery *p* or *p*′ furnishes the current for the microphone *m*, in the circuit of which the induction coil J is inserted. The arrangement, as described above, allows a uniform reception of the waves of sound by the microphones, independent of the duration of the performance and the position of the singers. The reproduction of these

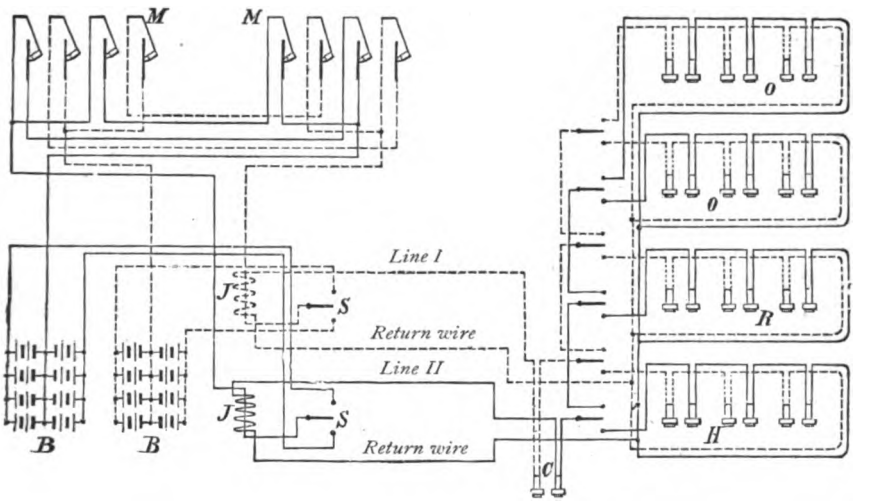


Fig. 725.—The Telephonic Transmission of Music at Vienna.

waves in the different telephones of the listeners is brought about by the peculiar mode in which the telephones are joined with the secondary coils of the induction coils. The ends of each secondary coil, as for instance of J′, are connected with the corresponding cable K′, which leads from the opera-house to the listeners'-room. One of the ends of the induction coil is connected with the commutator C as well as with *c*′, and the other end is simply joined to the leads leading to the telephone. If, for instance, connection of the cable is made with room 2 by means of the commutator *c*′, the undulating induced currents from the coil J′ reach the series of telephones indicated by II, and pass through their circuit in the direction indicated by the arrows. The currents from the coil J reach the telephone line I, and pass through it in the direction of the doubly-barbed arrows. As J_1 is induced by the undulating currents of the microphone *n*, and J by those of the microphone *m*, if each listener receive a telephone of row I, and also one of row II, he will be able to hear equally well whether the

singer is to the right or to the left of the prompter's box, or if opposite to it. All the microphones being connected in this manner with the telephone couples, this holds good for each listener.

Fig. 725 shows the connection of the Royal Opera with the Rotunda of the Exhibition building during the Exhibition of Vienna, 1883. This telephonic transmission of music was undertaken by the Private Telegraph Company after the plans of their engineer, A. Kittel. M M represent the microphones, B B their batteries, J J the induction coils, H R O the telephones. The twelve microphones placed at the opera-house were divided in two groups, each group consisting of six, or of three couples of microphones, joined parallel, so that each couple consisted of a microphone placed at the right side of the stage and a microphone placed at the left side. Only eight microphones are drawn in the figure, forming two groups of two couples. To maintain the current for the microphones and the induction coils constant, commutators S S are inserted into the primary circuit, so as to allow of the insertion of a fresh battery in the place of the exhausted battery.

The leads from the Rotunda terminated at the office where the control telephone C and the apparatus for the office correspondence were placed. Each of the cells O O contained sixteen telephone couples for the transmission of the opera music. The cell R contained thirty telephone couples for the transmission of the music from the Vienna Rollschuh Club (distance three and a half kilometres). H was a box containing seven telephone couples, reserved for visitors. In each auditorium the telephones of one circuit were joined in series, and every telephone couple contained a telephone of each of the two circuits.

SPECIAL APPLICATONS OF THE TELEPHONE AND MICROPHONE.

Police Use of the Telephone.—The telephone plays an important part in the police system at Chicago. Each policeman is in a position to communicate at once or within a few minutes with his own or the central station; trustworthy citizens are also in a position to call for help; and as thieves, as a rule, know when and where policemen are present, and arrange their plans accordingly, and policemen are seldom where they are wanted, such an arrangement is of great value. At certain points of each district police stations are erected, where there are three men, one horse, and a wagon always ready; and these stations are put into telephonic connection with alarm stations, which are similar in form to sentry-boxes. These boxes, which are just large enough to admit one person, are placed in the different streets at certain intervals, and can be opened by means of keys in the possession of policemen and respectable inhabitants of the town. To prevent misuse the keys are numbered, and once placed in the lock, can only be removed by the police. The box contains a pointer apparatus and a locked case, which can only be opened by the policeman, and in which the telephone apparatus is kept. The pointer apparatus, which is shown in

Fig. 726, is capable of sending eleven different signals: Police wagon, thieves, forgers, riot, drunkard, murder, accident, violation of city property, fighting,

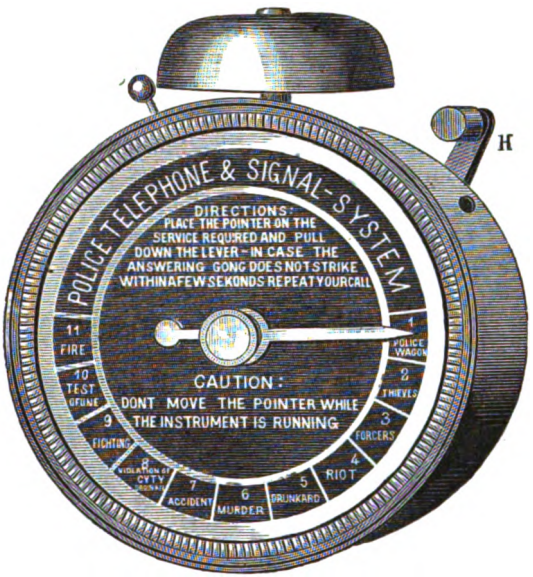

POLICE TELEPHONE & SIGNAL-SYSTEM
DIRECTIONS:
PLACE THE POINTER ON THE SERVICE REQUIRED AND PULL DOWN THE LEVER - IN CASE THE ANSWERING GONG DOES NOT STRIKE WITHIN A FEW SEKONDS REPEAT YOUR CALL
CAUTION:
DONT MOVE THE POINTER WHILE THE INSTRUMENT IS RUNNING
H
1 POLICE WAGON
2 THIEVES
3 FORGERS
4 RIOT
5 DRUNKARD
6 MURDER
7 ACCIDENT
8 VIOLATION OF CITY PROPERTY
9 FIGHTING
10 TEST OF LINE
11 FIRE

Fig. 726.—Chicago Police Signal.

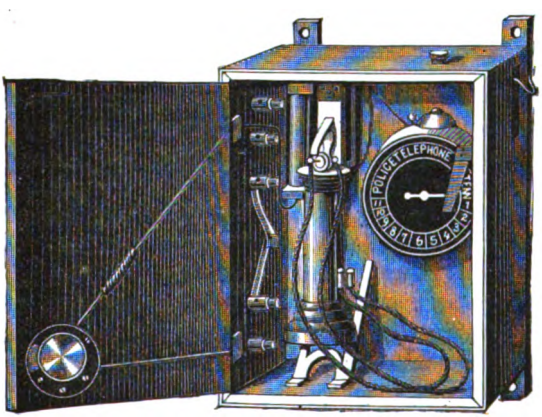


Fig. 727.—Chicago Police Telephone.

test of line, fire. The one who gives the signal has only to place the pointer and press down the lever H. The receiving apparatus at the police station consists of an ordinary Morse apparatus. Fig. 727 shows the apparatus contained in the locked case. It contains a telephone and microphone, and allows the police-

man to communicate with his station, and the inspector making the round to send his reports at certain intervals through the telephone to his superior. At the request of townspeople the alarm apparatus may be erected for them at their houses or places of business; but, in these cases, the door-key, placed in a sealed envelope, is deposited at the police station, so that the policeman may enter the house of the person calling for help.

Military Use of the Telephone.—As the telephone, compared with the telegraph apparatus, requires no specially-trained men for the purpose, it is used with advantage for certain military purposes. In the practice of troops over a large area, orders can be communicated by telephone; for instance, to give the infantry opportunity to practise firing, movable targets are fired at with cartridges, and have to appear and disappear in different places at certain intervals.

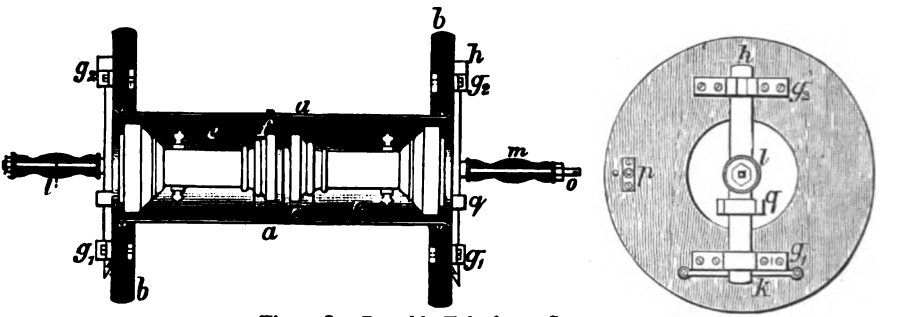


Fig. 728.—Portable Telephone Systems.

The officer in command must have a perfect control over these targets, and must be able to communicate with the persons that have to move them. Lieutenant Laffert reports that telephones are well adapted for this purpose. Siemens' telephones are generally used in these cases, and are connected by a cable, which consists of two copper wires of 0·8 millimetre, wound in lengths of 500 metres upon a portable roller, as shown in Fig. 728. The sheet-metal cylinder *a a*, which is 10 centimetres long, has two discs of hard wood *b b* fastened upon it; the disc *d* divides the cylinder into two halves *e e*, each of which contains a telephone; *f* is an opening in the sheet-metal cylinder, sufficiently large to allow the cable to come through. On the outside of the wooden disc nearest this opening the clamp *p* is fastened. The beginning of the cable is connected with the clamps of the telephone, the end with the clamp *p*. Straps are fastened to g_1 g_2, so that one man can conveniently carry the whole apparatus. When the apparatus is to be used, the portion *e*, which has not had its telephone connected with the cable, is taken out; the cable end is then removed from the screw *p*, and connected with the free telephone; two men take hold then of the handles *l m*, and walk quickly towards the place appointed.

In order to somewhat lighten the out-post service of troops enclosed in fortified places, A. Axt proposed the use of telephones combined with microphones. Suppose, for instance, the point A (Fig. 729) has to be guarded through a distance of 4,000 metres, along the arc U V of 65°. Microphones are sunk about one metre deep into the earth, at distances of 400 metres from each other, and the different leads are conveyed underground to the point A, where they are connected with a telephone. The microphones, which are constructed as shown in the right-hand figure, consist of cubes of tinned sheet iron of 3 millimetres thickness, open at one side. The metal membrane *m m* is arranged as in telephones. On the upper surface of the membrane a small carbon cylinder K is fastened, and against this a second carbon cylinder K′ is made to lean at an angle of about 80°. In order to make the contact of the carbons easily variable, the carbon K′ is hung from the line-wire *l* by means of a spiral spring. The leads of all the microphones are conveyed to the point A, where they are connected with the bars 1 to 12 of the commutator (Fig. 730). The second layer of bars is connected with the telephone T, the battery B, and a galvanometer G; one of the bars is also connected with an earth-plate E. It will now be an easy matter to trace the courses of the current when the connections are made by inserting the plugs in the proper places for the communication it is desired to secure. Suppose, for instance, that the bar 1 is plugged with *a* and *b* and the earth-leads, the current flows either from the battery through the galvanometer and the telephone to bar *a*, and so to the earth, or else from the battery through the bar *a* into the leads 1, into the microphone connected with 1, through its carbon cylinder K and metal mass into the earth. It will not be difficult to distinguish, by means of the telephone, whether single persons or troops, cavalry or artillery, are approaching the respective microphones. Instead of one telephone, several may be joined to the commutator.

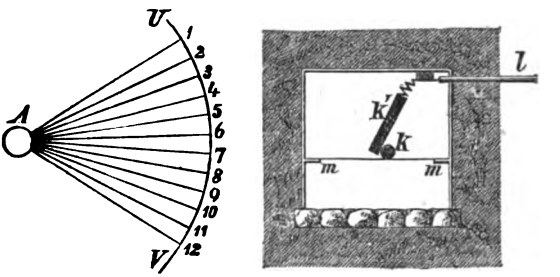


Fig. 729.—Military Microphone.

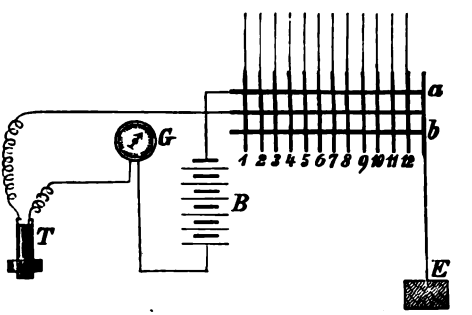


Fig. 730.—Commutator.

Divers' Telephones.—Fig. 731 represents a telephone specially devised by Captain Des Portes for divers. The telephone, which may be used both as receiving and sending apparatus, has the form of a round box B, in which a bent magnet is placed. The box is fastened to the plate *a b*, which is fixed inside the helmet. From the one clamp the wire leads to the helmet, which serves as earth-plate, whilst the wire from the other clamp S connects it with the cable K of the ship. The wire from S passes through the plate *a b*, and then through a gutta-percha plate *c*; the cable passes also through M, and a gutta-percha plate c_1. By this means the ends of both wires are insulated from the screw boxes R and M that contain them, and from the water outside these boxes. The two ends are brought into contact by means of small plates *n* soldered to the ends. When R and M are screwed together, the plates at *n* are pressed together, and thus close the circuit. When the diver puts on his apparatus the telephone is close to his left ear, and he can hear all that is spoken in the telephone at the surface. The diver is easily understood although the telephone is not immediately opposite his mouth when speaking, because his head is covered by the helmet. A whistle may be arranged in front of his mouth for purposes of signalling, and a single line which the diver carries with him serves the same purpose.

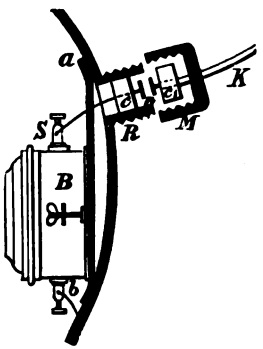


Fig. 731.—Diver's Telephone.

The Use of the Microphone for Medical Purposes.—The great sensibility of the microphone makes it of special service for medical purposes. A number of instruments have been constructed, of which we shall proceed to describe a few.

The Miophone, shown in Fig. 732, has been constructed by Boudet for examining the muscles. Behind the narrow opening of the mouthpiece B is placed the parchment membrane *m m*, which has upon its lower side the examining-knob K, and upon its upper side the carbon H. The second carbon D is held by the slide A, which can be moved up and down by the micrometer screw V. The bent paper strip at I serves as a spring which gently presses the carbon D against H. D is connected with the screw S by the support to which A is attached, and the wire shown in the figure connecting S with this support and H is connected with S_1 by means of a drop of mercury, which is placed in the hollow, and a wire. When a muscle is to be examined, the instrument is placed with its knob K upon it. In this manner it has been found that in a human muscle the pitch of the noise is suddenly raised with the natural contraction of that muscle, and continues to rise in proportion to the intensity of the contraction. The miophone is a very useful instrument for observing pathological cases, such as paralysis.

Microphones which are used for examining the pulse are generally called

sphygmophones. One of the most sensitive of these instruments is that constructed by Boudet, and shown in Fig. 733. Upon a gutta-percha plate 5 by 2·5 centimetres, two springs E and F are fastened, of which the one carries the examination knob K, the other the carbon H. The spring G serves to regulate the distance of the two springs from each other, and also the pressure of K

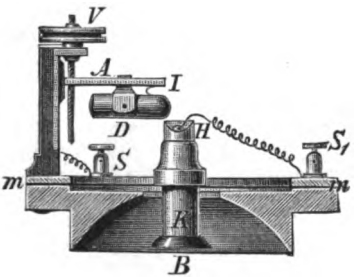


Fig. 732.—The Miophone.

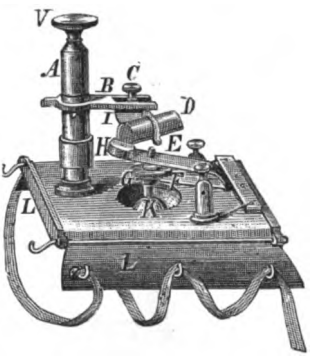


Fig. 733.—Sphygmophone.

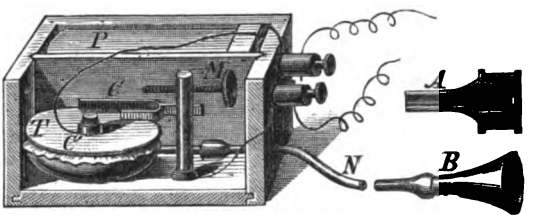


Fig. 734.—A Medical Microphone.

upon the artery. The movable carbon D is pressed by the paper spring I against the carbon H, and is fastened in the fork B by means of the screw C, which can be moved horizontally. By turning V, the fork, and with it the carbon, can be moved up and down A. To L L ribbons are attached, which can be tied to the arm or other portion to be examined.

For the examination of veins, where the instrument last described cannot be used, the transmission microphone is employed. This is shown in Fig. 734. The carbon piece C′ is fastened to the drum, the membrane (T) of which consists of prepared pig's bladder. The drum is in connection with an india-rubber tube N, and an ivory funnel B, which is placed with a slight pressure upon the vein to be examined. In order to exclude all noises from outside, the funnel is frequently provided with a membrane furnished with an examination knob (shown in section A). The regulation of the pressure of the contact between the two carbon pieces C C′ is brought about in the following manner:

The carbon C has on its upper surface a small steel needle, and the screw M is a magnetic steel spindle; the regulation of pressure is therefore due to the magnetic force of attraction. Gaiffe encloses the whole instrument in a box, which also contains the battery P.

The audiometer, or sonometer, shown in Fig. 735, is an extremely sensitive instrument used in testing the sensitiveness or acuteness of hearing in different persons. A rod marked with a scale is fastened upon two vertical supports; *a* and *c* are fixed induction coils, whilst *b* is a similar coil that can be moved along the rod; *a* has a good many turns of wire, whilst *c* has only a few. The ends of the coils *a* and *c* are connected with a microphone, so that the currents

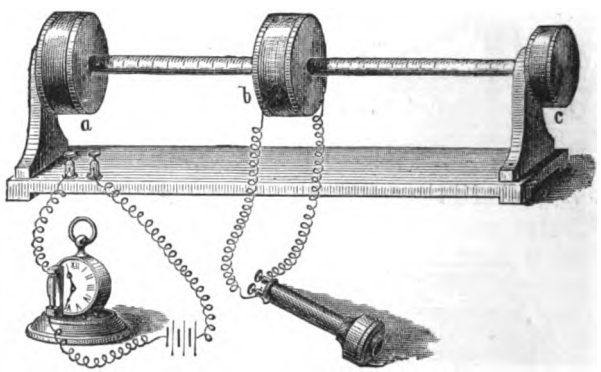


Fig. 735.—The Audiometer.

of the two coils *a* and *c* have opposite effects upon the coil *b*, which is connected with a telephone. If undulating currents are sent through the coils *a* and *c*, by means of the striking of a clock, both *a* and *c* will affect *b*, but *a* will affect it more strongly than *c* because it has a greater number of turns; thus the induction effects in *b* reproduce the striking of the clock in the telephone. But the induction effects of *a* and *c* are opposed to each other, and will consequently tend to neutralise each other the more completely the nearer the coil *b*, which has many turns, is brought to the coil *c*, which has but few. It is clear, however, that by moving *b* along the rod we must come upon a spot where the forces of *a* and *c* are in equilibrium, and where the telephone becomes mute. This position is indicated by o upon the scale, and when a person, whose hearing is to be tested, has the telephone at his ear, the nearer the coil *b* can be taken to this spot, without the listener ceasing to hear the clock, the better is the hearing of the person who is using the telephone. By examining a number of persons, say fifty for instance, a scale is obtained, for which the zero point indicates an extremely good hearing, and the end of the scale almost absolute deafness. Hughes and Richardson found that the sensitiveness of hearing

is increased when the breath is held, and that not only the hearing, but the strength of other organs, diminishes during illness.

The sonometer may further be used for measuring resistances. For this purpose the two coils *a* and *c* are made exactly alike, and the current coming from the battery is allowed to branch off, so that one branch flows through *a*, the other branch through *c*. The position of the coil *b* is determined when the telephone becomes mute. When the resistances on the two sides are exactly equal, this point will be the middle of the rod. It is evident that every alteration in the resistance of the one or the other branch will cause a noise in the telephone, which only ceases when the position of the coil *b* is altered accordingly. In this

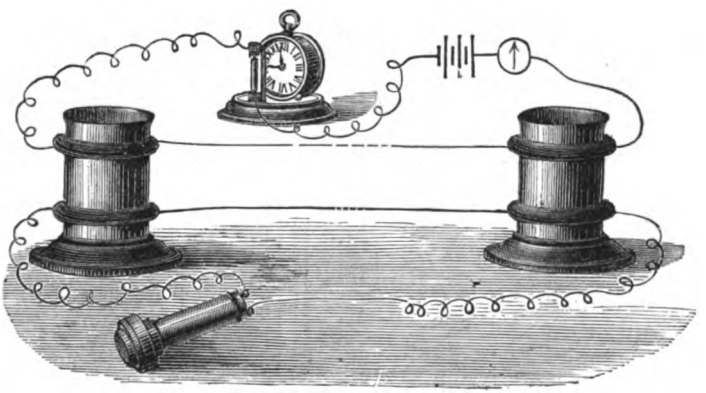


Fig. 736.—Hughes's Induction Balance.

manner a number of known resistances may be taken and marked along the scale. If an unknown resistance is now brought into the circuit, and the coil *b* moved until the telephone becomes mute, the position of *b* will thus indicate on the scale the value of the resistance. The sonometer may also be used for examining telephones. If a number of telephones in succession are inserted in the movable coil, which is placed at the zero point of the scale, that construction will be the best that proves most sensitive to the sonometer. The method of determining the relative sensitiveness of different telephones is the same as that of determining the sensitiveness of different persons' hearing. Telephones are here substituted for persons—that is to say, in the former case the telephone remained the same, while the listener was changed; but in this case the listener is the same, and the telephone is changed.

The Induction Balance.—The induction balance, shown in Fig. 736, is constructed on the same principle as the sonometer. The scales of this balance consist of two cylinders of ebonite, ten centimetres in height and three centimetres in diameter. Each of these has two coils of about 150 turns

each. The coils are arranged on the cylinders about half a centimetre apart. The two upper coils are connected with a battery, a microphone, and a galvanometer, to form one circuit, as shown in the figure, and the two lower coils are connected with a telephone to form a second circuit. The two lower coils are so arranged that the induced currents generated in them oppose each other, so that if the currents are equal to each other, no sound will be heard in the telephone. Suppose this condition of things to be secured, and then let a coin be introduced into one of the cylinders between its two coils, equilibrium is immediately destroyed, and the telephone begins to sound. It can be made mute again by adjusting the movable coil on the second cylinder, or by compensating for the disturbance in another manner. If a second coin be introduced

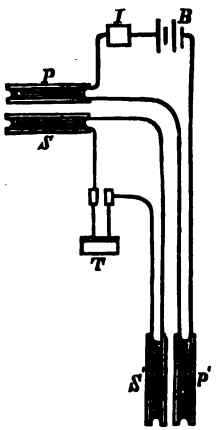


Fig. 737.—The Submarine Finder.

in the place of the first, equilibrium will only be maintained when the second coin has the same form, weight, and composition as the first. This method has been made use of for the examination of alloys, a description of which has been given in the *Philosophical Magazine*, 1879, and other periodicals. The balance is so sensitive that different results are even obtained when the physical condition of the coin only is altered, as for instance by hammering, casting, etc. The induction balance is further used for the discovery of ores underground, torpedoes and other metallic bodies in the sea, projectiles in the human body, etc. etc. MacEvoy's Submarine Finder, for the recovery of torpedoes, anchors, iron ships, and all kinds of iron material at the bottom of the sea, which is shown in Fig. 737, is only an induction balance in a somewhat altered form. P P′ are the coils inserted in the primary circuit, B represents the battery, and J an interrupter. The secondary coils S S′ are connected with the telephone T. When quickly succeeding current impulses are sent through the coils P P′, induced currents are generated in the spirals

s s', which neutralise each other, because they affect the telephone in opposite directions; thus the telephone is made mute when the position of the coils is regulated accordingly. If now the coils P' S' be brought near a metal mass, equilibrium is at once destroyed, and the telephone indicates by giving out sounds the presence of a metal in a particular spot—for instance, the spot where a torpedo lies hidden, etc.

The induction balance has been used in various forms by army surgeons as an electric ball probe. For this purpose Hughes makes one pair of the coils movable, and, having adjusted the balance, conveys this pair over the portion of the body into which the projectile entered. As soon as the coils come near the projectile, the telephone begins to sound. By moving the coils about this portion, the exact spot may be found where the projectile lies hidden, because the telephone will sound loudest at that spot. The depth of the projectile may also be detected. The coils for this purpose are left at that place where the telephone sounds loudest, it is then silenced by bringing a piece of lead, equal to that supposed to be in the wound, near the fixed coil. If the lead piece is at the same distance from the fixed coil as the coil on the body is from the projectile, equilibrium is again restored, and the telephone becomes silent. The distance of the lead from the fixed coil gives the depth to which the ball has entered.

Statistics.—The *Bulletin International* publishes the following statisics respecting the number of networks of telephones and of subscribers in Europe on the 31st December, 1885 :—

	No. of Networks.	No. of Subscribers.		No. of Networks.	No. of Subscribers.
Great Britain	89	15,114	*Brought forward* ...	287	61,253
Germany	91	14,733	Belgium	7	3,365
Italy	16	8,346	Austria.....	11	3,032
France	20	7,175	Holland	8	2,493
Sweden	15	5,705	Denmark	2	1,370
Russia	20	5,280	Spain	3	594
Switzerland	36	4,900	Portugal	2	350
Carried forward ...	287	61,253		320	72,457

No telephones have as yet been established in Turkey, Servia, Bulguria, Roumania, Greece, Montenegro, or the Grand Duchy of Luxemburg,

In Asia and Africa several networks of telephones have been established, viz., at Rangoon, Singapore, Columbo, Madras, Calcutta, Bombay, Maulmain, as well as in the Mauritius.

In Egypt, telephonic services have been established at both Alexandria and Cairo, and number 431 subscribers. In the United States the telephone is in general use, and the fifteen principal cities alone contain 30,000 subscribers. At Buenos Ayres there are 1,544 subscribers, and 389 at Monte Video.

PHOTOPHONE, PHEROPE, AND PHONOGRAPH.

Properties of Selenium.—In 1817, Berzelius discovered selenium, which in its chemical and physical properties resembles sulphur and tellurium. Selenium heated for some time to 1000 turns into a crystalline greyish mass. Knox pointed out, in 1837, the conductivity of molten selenium for electric currents. May found

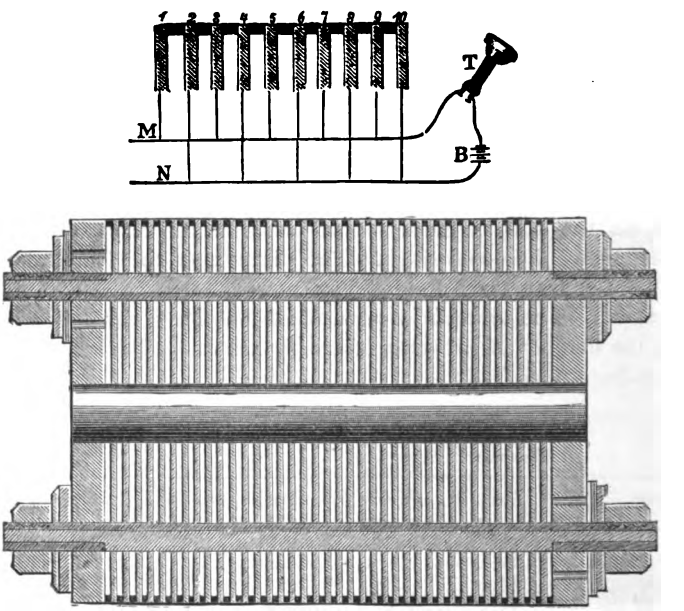


Fig. 738.—Bell's Selenium Cell.

that the conductivity of selenium is considerably influenced by light. Numerous physicists, as Willoughby-Smith, Draper, Sabine, Bell, Adams, Werner Siemens, and others have pursued investigations in the subject, most of them using the galvanometer for their experiments. Bell, however, used the telephone for detecting the alterations of resistance, and this led to the construction of the photophone. As selenium offers an unusually great resistance to the passage of the electric current, only very thin layers can be inserted in a circuit when the telephone is to be heard, because the resistance of the induction coil in the telephone has to correspond with the resistance of the circuit. The selenium surface has, however, to be large, in order that it may be as much as possible affected by the light. Bell and Tainter tried, therefore, to produce some preparation that

answered the above conditions—*i.e.* they endeavoured to obtain a sensitive selenium cell. Bell says, in his first memoir on this subject, that he had constructed more than fifty different selenium cells with which to experiment. Such a selenium cell is given in Fig. 738. It consists of a great number of brass discs (1. . . 10), which are insulated from each other by mica plates (the white strips in the figure). The mica discs have a smaller diameter than the brass discs, so that a circular space is left between two succeeding brass discs, which is intended for the reception of the selenium. The whole pile is now heated to the temperature at which selenium melts. A stick of selenium is then rubbed over the hot surface, and the molten selenium enters the circular spaces, marked in the figure as dark surfaces. The even brass discs are connected with a conductor N, and the odd numbered discs with

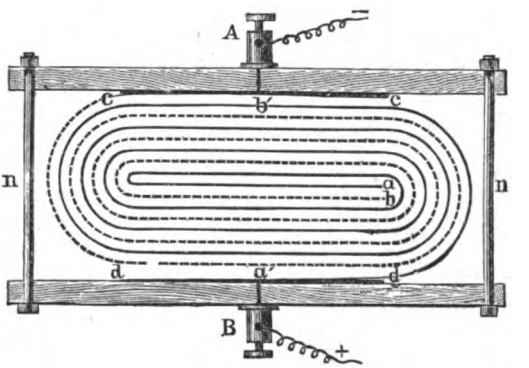


Fig. 739.—Mercadier's Selenium Cell.

a second conductor M. In this manner a number of selenium elements are joined parallel, that is to say, a pile is obtained, which is of small resistance, although its surface is large. Such a pile had 1,200 ohms of resistance in the dark, and only 600 ohms by daylight.

The form which Mercadier gave to his selenium element is shown in Fig. 739. Two very thin brass bands, *a* and *b*, of 0·1 millimetre thickness, are used for this purpose. The former is indicated by the full lines, the latter by the dotted lines. The brass bands are insulated from each other by having parchment strips between them, represented by the white spaces in the figure. The end of brass band *a* is fastened to the brass plate *d d*, and the strip *b* is connected with the brass plate *c c;* so that all the even coils are connected with one plate, and all the odd coils with the other. The complete coil is placed between wooden bars, which are held together by the screws *n n*. The clamp A is connected with the metal plate C C, the screw B with the plate *d d*. The block thus obtained is polished at its front side, and then tested with a galvanometer to see whether the two metal coils are insulated from each other throughout

their length. The block is then heated in a sand bath until it has reached the temperature at which selenium melts. One side of the block is then coated with a thin layer of selenium. In order to protect this layer of selenium, it is covered either with a thin mica plate or a layer of varnish.

If the telephone is to form a sensitive and effective apparatus for noticing the alterations of resistance in selenium, it must be influenced by currents that change their intensity suddenly and repeatedly, as gradual changes affect the telephone as little as they do the secondary coils of induction coils. It is therefore necessary that the resistance in the selenium shall change rapidly, *i.e.* that the selenium element shall be exposed to a rapidly intermittent illumination. Such intermittent changes of light can be produced in different ways; one method is to intercept the rays of light by means of an opaque disc, which has openings near its periphery, and is then made to rotate rapidly. If the selenium element be connected with a battery and a telephone to form a circuit, a sound will be heard in the telephone, the pitch of which is determined by the number of intermissions of the light in a unit of time. Bell and Tainter in their experiments placed the receiver 213 metres from the sender; if, however, the source of light is sufficiently powerful, this distance may be considerably increased. The apparatus, as described, allows correspondence to take place between persons at two places distant from each other, without their being connected with each other by leads. An alphabet may be composed of long and short sounds in the same manner as the alphabet of the Morse apparatus, which consists of strokes and points. A simple apparatus by means of which this may be obtained is shown in Fig. 740. The disc s, which is perforated at its periphery, is made to rotate uniformly, and thus changes the passing rays of light into intermittent rays, which, owing to the alterations of resistance in the selenium cell, cause the telephone at the receiving station to sound. These sounds may be made long and short at pleasure by preventing the rays of light from passing the disc s through a smaller or greater number of holes. The key T, which moves about L, and ends in the pointer L *l*, serves this purpose. When the key is at rest, *i.e.* when it presses against the upper screw V, the end of the pointer at *l* covers that opening of the disc which lies opposite the source of light, and hinders the passage of the rays of light. When the key is pressed down the pointer moves to the left, and the rays are allowed to pass as often as an opening comes opposite the source of light. By holding down the key a longer or shorter time, shorter or longer sounds are produced in the telephone at the receiving station.

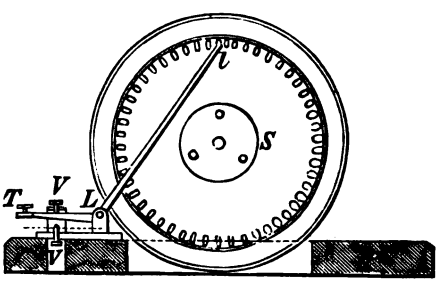


Fig. 740.—The Sender of the Photophone.

The Photophone.—To such apparatus, in which sound is produced by means of an ordinary ray of light, Bell gave the name of photophone. The photophone may not only be used for the transmission of sounds, but also for the transmission of spoken words. Bell obtained this result by making the beam of light, which a mirror reflects, vibrate, the vibrations being of the same kind as those produced by speaking to a membrane. Bell uses a thin mica or glass plate as membrane or diaphragm, which, by being silvered, serves at the same time as a mirror. The apparatus must be arranged as shown in

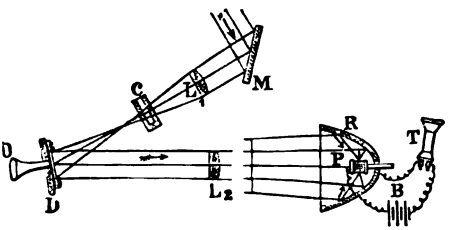


Fig. 741.—The Photophone.

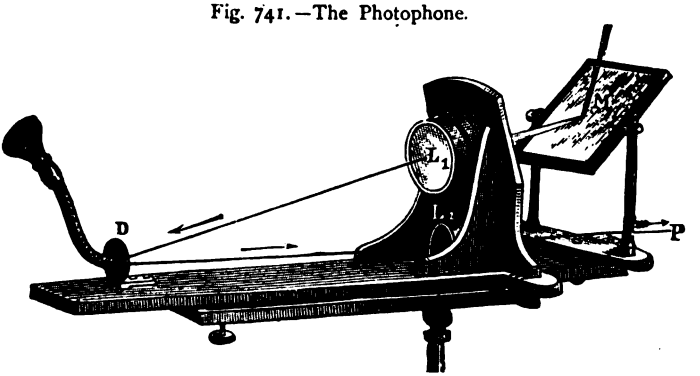


Fig. 742.—The Sender of a Photophone.

Fig. 741. M is a mirror, which throws the rays of light (of the sun, an electric lamp, etc.) upon the thin silvered plate or diaphragm D; these rays are reflected in the direction indicated by the arrow; the lenses L_1 and L_2 serve to concentrate the rays. At the receiving station the rays of light fall upon a parabolic concave mirror R, and are thrown from there upon the selenium cell P, which is inserted in the circuit of the battery B and the telephone T. If O is now spoken into, the diaphragm D begins to vibrate, and causes the rays of light to vibrate also. The selenium cell P will then be exposed to a change of illumination, which corresponds to the vibrations of sound. The resistance in the selenium cell, and therefore the current, is altered accordingly, and consequently the membrane of the telephone makes the same vibrations as the diaphragm D, *i.e.* the telephone reproduces the words spoken against D. Fig. 742 re-

presents the sender in perspective. The rays of light falling upon the mirror M are reflected, collected by the lens L_1, and conveyed to the mirror diaphragm D; from here they pass through the lens L_2, and then reach the receiving station.

Bell's experiments and publications regarding the photophone stimulated further investigations. It was found that the transmission of sound was possible without using selenium cells and galvanic batteries, and that non-luminous heat-rays were capable of producing sound. The latter fact caused Mercadier to use the word *Radiophone*, instead of photophone. A thin plate of any material serves as receiver in the radiophone, the sounds produced by this plate being transmitted by means of a tube to the ear. Mercadier altered the sender (or sounding apparatus) by substituting for the perforated disc a glass disc, covered with black paper, in which openings in the form of concentric circles were cut. By this arrangement those noises were avoided which, in Bell's arrangement, were caused by the friction of the air in the holes. It was soon found that the receiver's plates were not made to vibrate transversely by the intermittent rays of light, but vibrated like ordinary sounding-plates. One and the same plate, for instance, is capable of giving the highest and deepest notes equally well; the breadth and thickness of the plate do not influence the pitch nor the sonorousness or timbre of the sounds. When several intermittent rays of light, having varying velocities, meet the plate, whole sounds are produced by it. Except as it affects the intensity of sound, it is immaterial of what substance the plates are made; but the slightest alteration in the surface makes a considerable difference. Scratched or oxidised surfaces increased the intensity of sound very much, whilst a silvered glass plate gave no sound at all. As a rule, those plates proved most effective which absorb the rays strongly, but do not reflect them well. Very good results were obtained by using plates the surfaces of which were covered with Indian ink, platinum black, or soot; paper which in its ordinary condition gave no sounds, did so when the illuminated surface was covered with soot. A very sensitive receiver is obtained by coating a mica plate with soot.

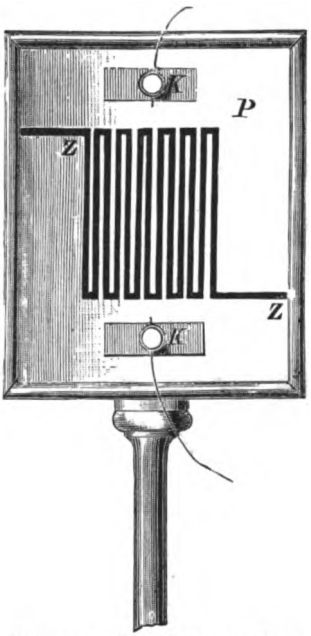


Fig. 743.—The Carbon or Soot Cell.

The great sensitiveness of surfaces coated with soot caused Tainter to form the idea of substituting soot for the selenium in a selenium cell. For this purpose silver is precipitated upon a glass plate P (Fig. 743); and portions of

this precipitate are removed, so that the places free from silver orm a zigzag line z z, which is filled up with soot. The zigzag-shaped soot strips divide the silver coating into two portions which can be connected, by means of the clamps K K, with the battery and the telephone. When intermitted rays of light strike upon the face of such a cell, loud sounds are produced in the telephone, the cause of which we shall now proceed to explain.

When use is made of a selenium cell, which is inserted along with a telephone in the circuit of a battery, the light-rays falling upon the selenium cell alter the conductivity of the selenium at the same rate as the intermittence of the rays. It follows that the current will also vary in the same way, and the telephone give out sounds, that is, the words spoken against the plate of the sender, which are the cause of the disturbance or intermission of the beam of light, will be reproduced in the telephone. By using a selenium cell the effect of light is made to produce sound.

Now when a simple plate, prepared as we have described, and furnished with a tube, is used as receiver, such as a mica plate covered with soot, neither battery nor telephone need be used. The illuminated surface of the receiver does not cause a second apparatus (the telephone) to sound, but it is the plate itself which sounds. The light effect, therefore, that takes place with the soot-covered mica plate is not in all respects similar to that in the selenium cell.

Several physicists have experimented in order to find out what constituents of light really act upon the plate, whether the light or heat rays. For this purpose intermittent rays were allowed to pass through a solution of iodine in sulphide of carbon, which has the property of absorbing the rays of light, but allowing heat-rays to pass. It was found that the sounding of the plate was not influenced by inserting the solution. The plate, however, emitted no sounds when, instead of the iodine sulphide solution, a solution of alum was used. The latter solution absorbs the heat-rays, but allows the rays of light to pass. Mercadier used a red-hot copper plate as a source of light for producing intermittent rays, and succeeded in making the receiver give out sounds. He then allowed the plate to cool gradually, so that it could be no longer seen in the darkened room —*i.e.* no luminous rays were sent out; in spite of this the sounding of the receiver remained still audible. From these and similar experiments it follows that the effect is not due to the light-rays, but to the heat-rays. Mercadier proved this by decomposing intermittent rays of light into their constituents by means of a prism; the spectrum thus received was examined by a receiver, the plate of which was covered up to a small slit. The different constituents of the intermitted light were examined in turns, and the same result obtained.

Although it is proved in this manner that heat-rays cause the plate of the receiver to vibrate, it is still necessary to ascertain the nature of these vibrations. It has been mentioned already that the plate of the receiver does not vibrate transversely as ordinary sounding-plates. Bell has given the following explanation: When the intermittent beam strikes upon the plate of the receiver, the particles are alternately heated and cooled; when they are heated they expand,

and consequently the intervals which are filled with air are diminished; when the light is intercepted the particles are cooled, and the spaces between them enlarged. Air is squeezed out from the interstices between the particles in the first case, and drawn in, in the latter; the enlarging of the intervals causes rarefaction of the air in the soot layers, and the outer air rushes in; the contraction of the intersticial spaces causes condensation and escape of the air they contain. These two effects are still further increased by the heating and cooling of the air in the intervals alternately, whereby the volumes are alternately increased and diminished. By these means alternate waves of compression and rarefaction are produced in the surrounding air, and it is to this that the sound which is emitted owes its existence.

Cause of the Microphonic Action of Selenium Cells.—The remarkable property possessed by crystalline selenium of having its electrical resistance varied by the action of light, has been the subject of many investigations. Of these the best known and by far the most exhaustive are the researches of Professor W. G. Adams and Mr. R. E. Day, an account of which was published in the *Phil. Trans.* of 1877. As the result of many experiments, these gentlemen were led to form the opinion that "the electrical conductivity of selenium is electrolytic." The principal reasons given for this conclusion are: "(1) that the resistance of selenium bars appeared to depend upon the E. M. F. of the battery employed, being generally diminished as the battery power was increased; (2) that the resistance of a bar A B was generally not the same for a current in the direction A B as for a current in the direction B A; (3) that the passage of a battery current was always followed when the battery had been disconnected by a secondary or polarisation current in the opposite direction, it being clearly proved that this secondary current was not due to any thermo-electric action, either in the selenium itself or in any other part of the circuit."

The action of light in altering the conductivity is supposed by these experimenters to arise from a modification of the crystalline condition of the substance when exposed to light. The following are their words on this point: "Light, as we know, in the case of some bodies tends to promote crystallisation, and when it falls on the surface of a stick of selenium, tends to promote crystallisation in the exterior layer, and therefore to produce a flow of energy from within outwards, which under certain circumstances appears in the case of selenium to produce an electric current. The crystallisation produced in selenium by light may also account for the diminution in the resistance of the selenium when a current from a battery is passing through it, for in changing to the crystalline state selenium becomes a better conductor of electricity."

Sabine, Siemens, Moser, Bidwell, and lastly Mr. C. E. Fritts, of New York,* have investigated and discussed these most remarkable properties.

Dr. James Moser's theory may be stated as follows:

There is always imperfect contact between the metallic electrodes and the

* See *Electrical Review* of March 7th, 1885.

selenium, which together constitute a so-called "selenium cell." Selenium reflects the invisible portions of the spectrum, absorbing principally the visible or illuminating rays, the vibrations thus taken up assume the form of heat, and the temperature of the selenium cell is thereby raised.* In consequence of this rise of temperature the selenium expands; it is accordingly pressed into closer contact with the electrodes, and, as in the case of the microphone, the resistance of the system is proportionately diminished. When the cell is screened from the light, the absorbed heat is quickly radiated away; the selenium contracts to its former volume, and the original degree of resistance is restored. Thus, according to Dr. Moser's paper, the whole mystery is easily and completely explained.

Respecting this explanation, Mr. Shelford Bidwell remarks that the theory can be submitted to a very simple and conclusive test. If it is true that the observed effects are due merely to a rise of temperature, then it is clearly immaterial whether such rise of temperature is brought about by the heating action of light, or by the direct application of heat in the ordinary way. Instead of exposing a selenium cell to the light, let it be enclosed in a dark box and warmed over a gas-burner; then, if the theory be correct, the resistance of the cell should at once begin to fall. This, however, is not found to be the case. Mr. Bidwell had in his possession a number of selenium cells the resistance of which is immediately diminished by the smallest accession of light; but in the case of all of them (except one) the immediate effect of the direct application of heat is not a fall, but a rise in the resistance. When the temperature of the cell reaches a point which is in general a few degrees higher than the average temperature of the air a maximum resistance is attained; and if the heating is continued the resistance begins to decrease.

Mr. Bidwell maintains that the supposition that light produces its effects by heating is further negatived by the fact that a comparatively high degree of temperature is required to bring down the resistance of the cell to the point to which it is instantly reduced by exposure to a strong light. When a selenium cell is for a moment exposed to sunlight, it does not become perceptibly warm to the touch; but the amount of dark heat necessary to effect the same reduction in its resistance as is caused by a moment's sunshine, would certainly render it too hot to handle.

The best results with a selenium photophone are said to be obtained when the heat-rays of the spectrum are excluded, as by filtering the beam of light through a solution of alum. Dark radiation does indeed, *per se*, diminish the resistance of selenium; but the diminution due to dark radiation is to some extent masked by the rise of temperature which accompanies it, and which generally tends to produce the opposite effect. In its peculiar sensitiveness to the visible part of the spectrum, selenium seems to stand almost alone.

In the case of the carbon photophone there can be no doubt that the effects

* "Selenium," Dr. Moser says, "is heated by light."

are due to heat only. In the recent publication by Mr. C. E. Fritts, above referred to, a new and ingenious method of constructing selenium cells has again directed attention to the subject, and led to the discovery that sulphur exhibits a similar behaviour when under the influence of light, though not to the same extent as selenium.

The Telephote, or Pherope, is an instrument to which the ambitious purpose has been assigned of enabling a person living, for instance, in London, to see by telegraph a picture or an occurrence, such as a race, taking place at York. Although the problem is far from being solved, Messrs. Ayrton and Perry have been able to show that it is within the range of possibility. We cannot do better than give a quotation from a lecture by Professor Perry on this subject :—" I have a little selenium cell at York on a certain part of this picture, and at London I can throw at a corresponding place on this screen a square of light; and suppose that the illumination of this square is governed by a little movable shutter, which is attached to the needle of a galvanometer. Now when light falls on the selenium at York, an immediate change occurs in it, so that more current flows to London, and this opens the shutter. The London square is then bright when the York selenium is in bright illumination. When the York selenium is in shade or darkness, you see that the London square is in corresponding shade or darkness. (Experiment shown.) Now suppose that we form an image of this girl with her skipping-rope at York, and cause a selenium cell at York to travel across her image, and suppose that this mirror at London moves so as to cause the illumination which passes the shutter to traverse this London screen isochronously — an operation performed in several telegraph instruments. Then, whenever this cell reaches a dark, or shady, or bright place in the image at York, there will be darkness, or shade, or brightness at the corresponding place in London. And now suppose that this motion is effected rapidly enough, you are all aware that if the shutter is only quick enough in its answering motions, the image of the part of the screen at York traversed by the cell will be faithfully reproduced, and will remain on the retina at London as a distinct picture in black, and grey, and white, just like a photograph. With then, perhaps, forty such cells as this all moving in the way spoken of, or a smaller number rotating on a radial arm, it would actually be possible to show at London, not merely an image of a girl at York, but an image of a girl skipping."

Professor Perry used the model shown in Fig. 744 to explain the principle. By means of a lantern L an image is thrown upon the screen S: for instance, a ribbed pattern consisting of dark and light stripes. By means of a string a selenium cell D can be moved quickly over it; one end of this string is fastened to the movable sector *h b*, so that the selenium cell and this sector, by pulling the free end of the string, are moved perfectly isochronously. The mirror *a* is fastened to the support *b;* opposite to the mirror is placed the screen *s*, bent to the radius of *h b*. The source of light *c*, the rays of which are thrown by the mirror upon screen *s*, has a peculiar construction; before the rays reach the

mirror they have to pass a kind of galvanometer, *i.e.* they have to go through the hollow of a coil in which a small magnetic needle swings. Upon this needle is fastened a screen of sheet aluminium, coated with lamp-black, called a darkener, which places itself, according to the position of the needle, either crosswise or parallel to the longitudinal direction of the space of the spiral, or takes up a position between the two. When the darkener stands crosswise in the hollow space of the spiral, it entirely cuts off the passage of the rays of light; when it stands parallel, almost all the rays are allowed to pass; and in its middle position, a portion only of the rays pass. But as the coil is inserted, with the selenium cell D, in the circuit of a battery, the position of the magnetic needle, and also that of the darkener, will depend upon the strength of current. The darkener is fastened upon the magnetic needle in its crosswise position, that is,

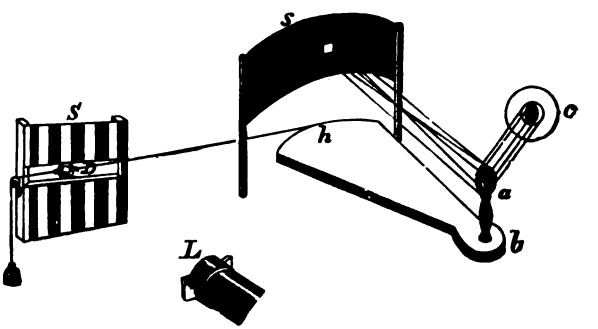


Fig. 744.—The Telephote, or Pherope.

when the rays of light are completely intercepted, and when the current has its minimum intensity. By this arrangement the strength of current is only varied by the varying resistance of the selenium cell, which varies with the illumination. If, therefore, the selenium cell happens to be upon a light stripe of the screen *s*, its resistance will be least, and the strength of current greatest; the darkener will, therefore, place itself parallel to the longitudinal direction of the hollow space in the coil. The rays of light, which are allowed to pass freely, then fall upon the mirror *a*, and are thrown from there upon the screen *s*, and a light stripe will be produced. If the selenium cell is moved till it reaches the next light stripe, the mirror *a* will again produce a light stripe upon screen *s*; the position of the light stripes upon *s* will have to correspond to those with S, because the selenium cell D and the mirror *a*, fastened upon *h b*, are moved in the same manner. As often as the selenium cell reaches a dark stripe its resistance becomes highest, therefore the strength in the coil lowest. The darkener then places itself crosswise, and allows no rays of light to fall upon the mirror *a*; the screen *s*, therefore, will also remain dark. By moving then the selenium cell D over the picture on the screen S, corresponding pictures might be produced on the screen *s*. A

faithful copy of the image of S will be produced on *s*, when the selenium cell is moved so quickly that the produced light stripes on *s* succeed each other at shorter intervals than those required by the human eye to perceive the several pictures separately. The image of the second and third light stripes will be already on the screen, while the impression of the first remains still on the retina.

It need hardly be said that the synchronous motion of mirror *a* and selenium cell D would have to be brought about by other means than a string, as in the model; for this purpose the phonic wheel might be used, for instance. For the reproduction of a larger picture, such as a skipping girl, a greater number of selenium cells are required, and the sources of light have to be arranged accordingly.

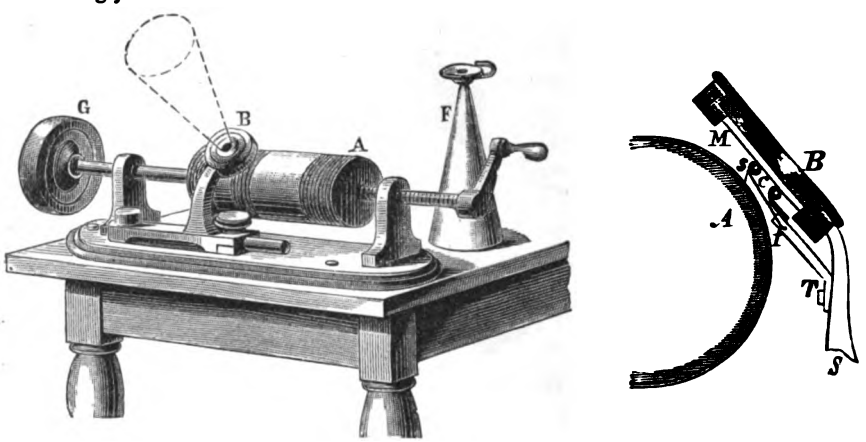


Fig. 745.—Edison's Phonograph.

The Phonograph.—We shall conclude the chapter on Telephony with the description of the Phonograph, not that electricity is in any way concerned in its action, but because of its close relationship with the telephone; and because it proves that the oscillations of a tympanum, like the disc of a telephone, in one direction only, are capable of producing all the effects of sound.

The phonograph was invented by Edison, and one of the forms which he gave to it is shown in Fig. 745. The brass cylinder A is fastened upon a shaft, one end of which has a handle, and the other end a heavy fly-wheel G. In one half of the axis, namely, that nearest the handle, and in the brass cylinder, screws are cut, the threads of which are exactly alike—that is to say, the threads on the cylinder are exactly of the same breadth as those of the shaft, so that the same number in both go to the inch. As the screw axis lies in a female screw fastened to the support, when the handle is turned the cylinder will be moved in the direction of the axis. A movable support S is placed on the frame of this apparatus, which carries a mouthpiece B with a

membrane M, arranged and fastened to each other, as in telephones. The spring *f* is screwed at one end T to the support S, and carries at its free end the steel pin *s*. The connection of this elastic pin with the membrane is brought about by means of the india-rubber tube *c*. When the membrane M is made to vibrate by speaking into B, *s* vibrates in the same manner. To register speech with this apparatus the brass cylinder is covered with tinfoil, or a thin copper plate; the pin *s* is then adjusted, and the cylinder made to rotate, whilst at the same time words are spoken into the mouthpiece. The membrane, and with it the pin, begin to vibrate, the latter tracking signs upon the moving tinfoil, which correspond to the vibrations produced by speaking. The worms of the cylinder and its axis being alike, the pin travels with the same velocity from the one to the next thread as the cylinder, by means of its screw axis, moves sideways. If the phonograph is to reproduce the words spoken, the pin is taken off and the cylinder moved back until it arrives at the commencement of the coil; the pin is then again placed on the cylinder, and the latter is made to rotate with the same velocity and in the same direction as before. The effect of the apparatus is increased when the funnel F is placed upon the mouthpiece. The pin, by going over the signs it traced before, will reproduce the spoken words; that is to say, it will vibrate again as it did when words were spoken in the mouthpiece, and will cause the membrane to vibrate. The membrane reproduces the words audibly, and may be heard in every part of a large room.

THE ELECTRIC TELEGRAPH.

History of Telegraphy.—Experiments in telegraphy were made as far back as the year 1753, when it was proposed to represent letters by combinations of sparks, etc.; but these were of little practical value before the discovery of the galvanic current.

The earliest proposal to use the transmission of electricity for the communication of signals appears in the *Scots' Magazine* for February, 1753, where a correspondent from Renfrew, who signs himself C. M., proposes several kinds of telegraphs acting by the attractive power of electricity, conveyed by a series of parallel wires, corresponding in number to the letters of the alphabet, and insulated by supports of glass or jewellers' cement at every twenty yards. Words were to be spelt by the electricity attracting letters, or by striking bells corresponding to letters. One Le Sage, of Geneva, in 1782, proposed to convey twenty-four insulated wires in a subterranean tube, and to indicate the letters of the alphabet by means of the attraction of light bodies. In 1811 Sömmerring suggested a similar application of voltaic electricity, chemical decomposition being the effect observed; and as, to a certain extent, he carried his suggestion into effect, he is sometimes regarded as the first who made a practical telegraph.

Samuel Thomas Sömmerring was born in 1755, at Thorn, studied medicine at Göttingen, and became professor of anatomy at Kassel. His many and valuable investigations give him a place among the first of German anatomists. Sömmerring was led by a suggestion of the Minister Montgelas to use the galvanic current in telegraphy in the following manner:—When the Austrian troops crossed the Inn, 1809, and entered Bavaria, King Maximilian fled, in company with Montgelas, to Dillingen; here he was surprised by the unexpected arrival of Napoleon. At this time Chappe's optical telegraph was used in France, and through it Napoleon had obtained the news of the crossing of the Austrians sooner than had been expected, and the consequence was that Munich, which had been taken on the 16th of April, was retaken by Napoleon on the 22nd of April, so that Maximilian was able to return to his capital the same month. The prominent part which the method of signalling had played in this important event, caused Montgelas to ask the Academy to lay proposals before him for a system of telegraphy. Although Montgelas can only have had in mind the optical telegraph, Sömmerring conceived the notion of making use of the electrolysis of water by the galvanic current for this purpose. His experiments commenced on July 8th, 1809. On the 6th of August he telegraphed through a length of wire of 724 feet, and on the 18th of August through a wire 2,000 feet long. His apparatus is shown in Fig. 746. It contained twenty-seven wires for the twenty-five letters, together with stop and repeating signs. These wires were covered with an insulating substance, and twisted so as to form a cable. One end of

each wire ended in a gold pin, which was cemented in the bottom of a rectangular flat glass box filled with water; the other end was connected with a frame containing twenty-seven connecting pivots, each of which was lettered. A voltaic pile, consisting of fifteen Brabant thalers, zinc discs, and felt impregnated with a solution of ordinary salt, was used as a battery. The poles of this battery ended in plugs, which were inserted in two holes of the pivots, and hydrogen and oxygen were then evolved at the corresponding gold pins, and by seeing at which pole the gas was produced the observer told

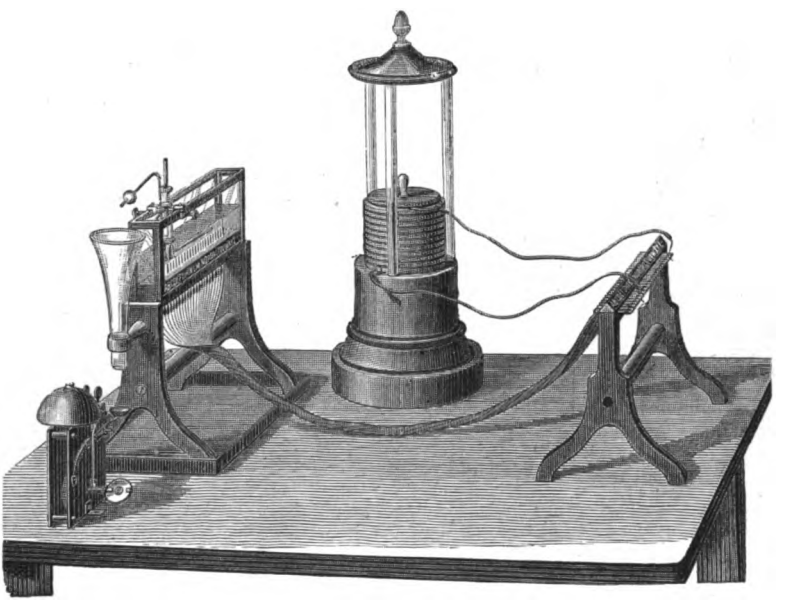


Fig. 746.—Sömmerring's Telegraph.

which letter it was intended to signal. Sömmerring further combined with this apparatus an alarm, as shown in the figure. A spoon-shaped glass vessel, placed so as to catch the escaping H and O of two gold pins, was connected with an angular lever; the horizontal arm of the lever reaching out of the glass box loosely supported a leaden ball. When the evolution of gas commenced the spoon was raised, and the protruding arm of the lever was lowered, and the leaden ball allowed to fall through a glass funnel upon the lever of a clock, which made the bell ring. Sömmerring's apparatus was never applied to practical use.

In 1819 the deviation of the magnetic needle through the action of an adjacent galvanic current became known, and Ampère, in 1820, and Fechner, in 1829, showed how to make use of this fact for telegraphic purposes. Ampère's

plan was to use thirty needles and sixty wires; Fechner's, twenty-four needles and forty-eight wires; for at first it was supposed that there must be a separate needle for each letter or sign signalled; these proposals, however, came to no practical results.

Baron Schilling constructed an electro-magnetic telegraph in 1832, by making use of the multiplier devised by S. Ch. Schweigger; but the first electro-magnetic telegraph of which practical use was made, was the telegraph constructed by Gauss and Weber at Göttingen, in 1833, with a line of 3,000 feet.

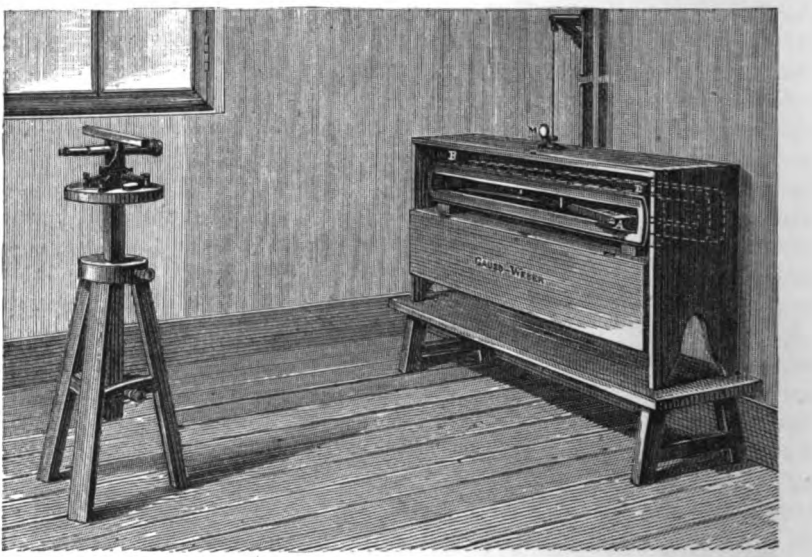


Fig. 747.—Gauss and Weber's Telegraph.

Johann Carl Friedrich Gauss was born in 1777 at Braunschweig; he studied at Göttingen, and was a pupil of T. F. Pfaff. In 1807 he was appointed Professor and Director of the Observatory at Göttingen. Wilhelm Edward Weber was born in 1804, at Wittenberg. He studied at Halle, and published in 1825, jointly with his brother, Ernst Heinrich, his classical work, *Die Wellenlehre*. He was introduced to Gauss by A. v. Humboldt, and through his influence obtained the post of Professor of Physics at Göttingen..

Their original apparatus was sent to the Exhibition at Paris in 1881, and has been described in *La Lumière Électrique* (vol. viii.). It is represented in Fig. 747. B B is a galvanometer frame in which the magnet A of 1·21 metres in length is suspended by means of a silk thread, and carries a small mirror M. The sender consisted at first of a simple galvanic battery, for which the induction apparatus shown in Fig. 748 was afterwards substituted. Two large magnets A, each weighing 25 pounds, were arranged vertically upon a frame

so that their north poles projected above the frame. The induction coil B was placed loosely about the middle of the magnets so that it could be moved freely by means of handles. The ends of the coil B were connected with the coil in the galvanometer frame. A quick motion of the coil generated an induced current, which reached the galvanometer frame through the wires, and caused the magnetic rod to be deflected. The direction of deviation was determined by the direction in which the coil was moved, and it is evident that by combinations of these deflections a whole alphabet could be formed. To simplify the manipulations, a double lever L was added, which moved a commutator as well as the coil. The call signal was given by means of a bell and clockwork.

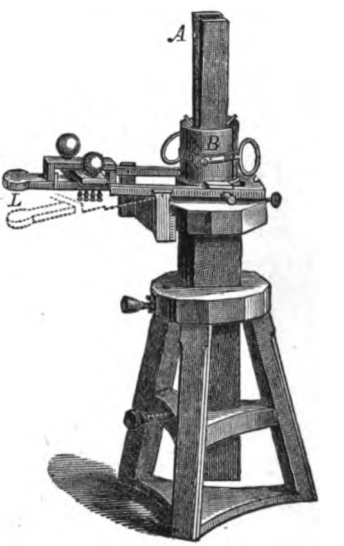


Fig. 748.—Gauss and Weber's Sending Apparatus.

Although Messrs. Gauss and Weber's communication of signals at Göttingen in 1833 was the first accomplishment of telegraphic communication by means of electricity, and realised the fancy of Strada, quoted by Addison, of sympathetic magnets, yet their invention was regarded merely as an appendage to a magnetic observatory, and several years elapsed before we hear more of the new invention. The year 1837 is the date of the realised electric telegraph. We find three distinct claimants, of whose independent merits there is no reason whatever to doubt, though how much of the merit of all must be considered due to Messrs. Gauss and Weber, who first made the experiment described above, though they did not offer it for general adoption in a convenient form, is a matter which we need not here attempt to decide. The three independent inventors are Carl August von Steinheil, of Munich, who had been a pupil of Messrs. Gauss and Weber; Mr. Wheatstone, of London; and Mr. Morse, of the United States. The telegraph of the two last resembles in principle Oersted's and Gauss's; that of the first is entirely original, and consists in making a ribbon of paper move by clockwork, whilst interrupted marks are impressed upon it by a pen or stamp of some kind brought in contact with the ribbon by the attraction of a temporary magnet, which is excited by the circulation of the telegraphic current of electricity. In the telegraph of Mr. Wheatstone, the needle moves only to the right or left, and by the combination of a certain number of right and left motions, either with one or two independent needles acted on at once by distinct currents, the alphabet is easily, though somewhat tediously, constructed.

It thus appears that we cannot claim the exclusive invention of electric telegraphy for any one individual. But of the several inventors none probably

has shown such perseverance and skill in overcoming difficulties as Mr. Wheatstone. His telegraph, accordingly, was in general use in England before Von Steinheil was able to obtain a similar success in Germany. The telegraphs of Mr. Morse have this inestimable advantage, that they preserve a permanent record of the despatches which they convey. We will now examine the points of difference of the earliest instruments of these several inventors more in detail.

Carl August von Steinheil was born in 1801; he studied science first at Göttingen under Gauss, and then at Königsberg. He was appointed in 1835

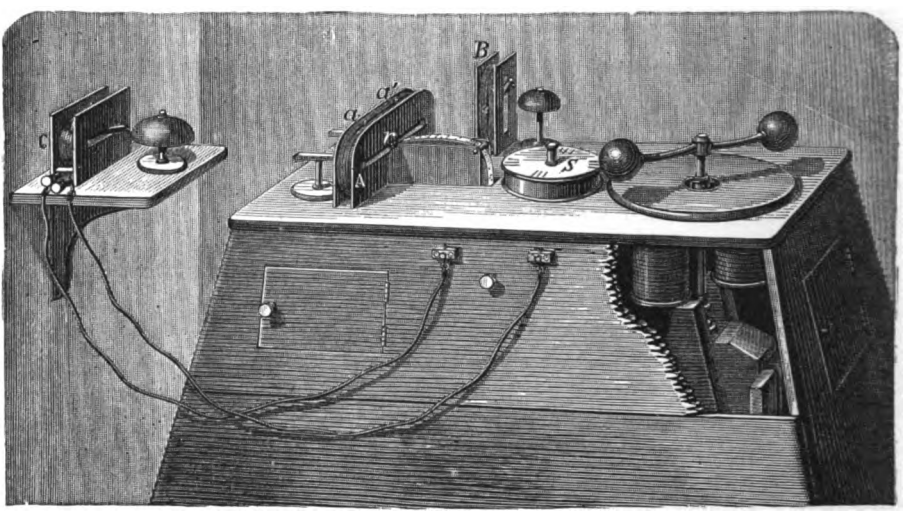


Fig. 749.—Steinheil's Telegraph.

Professor of Physics and Mathematics at Munich. In 1849 he was invited to Vienna by the Austrian Government, to superintend the establishment of telegraphic communications, and there he prepared a complete telegraph system for the different provinces of the empire. When he returned to Munich, in response to the wishes of the King Maximilian II., he founded in 1854 the optical and astronomical laboratories which have since become so famous, and became a member of many different scientific societies. He died in 1870.

Steinheil undertook the further perfection of the Gauss-Weber telegraph, and in his hands the apparatus became the first writing telegraph, which is shown in Fig. 749 (*La Lumière Électrique*). The sending apparatus consists of a kind of Pixii's machine (which may be seen on the right in the figure, where a portion of the case is removed for the purpose). In this generator the induction coils can be moved past the magnet-poles by means of a

horizontal lever weighted with balls. The induced currents thus obtained receive the one or the other direction, according to the direction in which the coils are moved. The receiving apparatus consists of a galvanometer frame A, in which there are two magnetic needles, which turn about the vertical axis $a\,a'$. Each has a colour-pot, or small ink-holder, and a small brass adjustment, and is held in a certain position by a controlling magnet. When a current flows in one direction through the coil, the brass adjustment of one of the needles strikes against a bell; if the current flows in the other direction, the brass piece of the second needle strikes against the second bell. In the same manner a current of one direction passes the ink-holder of one needle, and a current of the other direction the ink-holder of the second needle, against a paper strip r, which by means of some wheelwork is moved with uniform velocity past the two holders. The bells are not drawn in the figure. When the bells are used the alphabet is formed by a combination of strokes; when the ink-holders are used, by combinations of points; as for instance $s = \ldots$, $t = :$, $e = .$, $n = ..$, and so on. The two alarms B and C, also shown in the figure, consist simply of a coil in which a magnet swings about a vertical or horizontal axis, and strikes against a bell. Steinheil used this instrument for corresponding between the Observatory at Bogenhausen and his private residence at Munich, the total length of the wire being 37,500 feet.

Steinheil it was who further discovered the possibility of conveying the returning electric current back through the earth, a discovery which was of the greatest utility in the further development of telegraphy: indeed, no discovery is perhaps more deserving of notice on account of its importance, than this of the apparently infinite conducting power of the earth, when made to act as the vehicle of the return current. Setting all theory aside, it is an unquestionable fact that if a telegraphic communication be made, suppose from London to Brighton, by means of a wire going thither, passing through a galvanometer, and then returning, the strength of the current shown by the galvanometer at Brighton will be almost exactly doubled if, instead of the return wire, we establish a good communication between the ends of the conducting wire and the mass of the earth at Brighton and London. The whole resistance of the return wire is at once dispensed with. The fact was more than suspected by Steinheil in 1838; but, from some cause or other, it obtained little publicity; nor does the author appear to have exerted himself to remove the reasonable prejudices with which so singular a paradox was naturally received. A most ingenious inventor, Mr. Bain, whose chemical telegraph we shall describe, independently discovered the principle, and proclaimed its application somewhat later; and in 1843 perhaps the first entirely convincing experiments were made by M. Mattiucci, at Pisa. From this time the double wire required to move the needle telegraph was reduced to a single one. The explanation of this curious fact appears to be, not that the electricity is conducted back by the earth to its origin at the battery, but that the molecular disturbance communicated along the conducting wire, in consequence of the difference of potential

produced by the battery being effectually relieved by perfect communication with a vast reservoir of zero potential and infinite capacity like the earth, proceeds in an uninterrupted manner, and to an unlimited extent.

Meanwhile the needle telegraph had undergone some further modifications. William Fothergill Cooke, who had seen Schilling's apparatus in 1876 at Professor Munke's house in Heidelberg, copied it, and brought it to England. Intent on improving the apparatus, he joined Wheatstone, and together they constructed a needle apparatus with four, and another with five needles. The latter

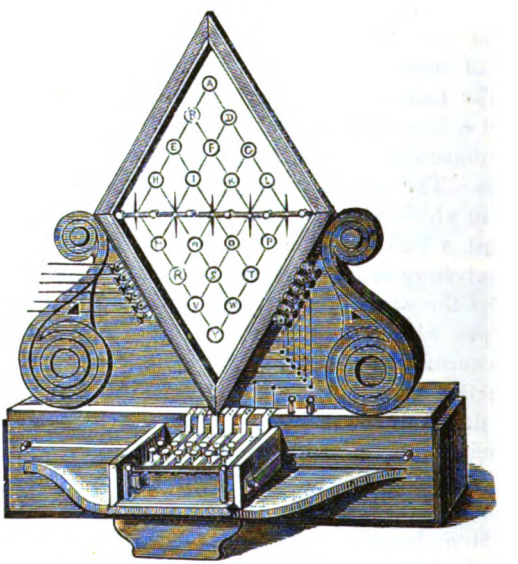


Fig. 750.—Cooke and Wheatstone's Five-Needle Telegraph.

is represented in Fig. 750. The signs were given by the deviation of two needles at the same time. As may be seen from the drawing, twenty different signs could be given by the apparatus. Cooke and Wheatstone took out their first patent in 1837. It is important to note that a local circuit was used for working the alarm, as this represents the first application of a transmission apparatus, the so-called relay. By inventing the relay, the principle of which is that a current too weak to do the work itself, may cause a strong local current to do the work for it, Wheatstone made it possible to telegraph on long lines with comparatively weak currents, only just strong enough to close the local battery by means of the relay, which does the real work, and sets the receiving apparatus in motion. The relay was first used with the alarm only, in the form shown in Fig. 751. The current coming through *l l'* passes the coil M, disturbing the equilibrium of the magnetic needle, movable about the axis *x y*,

and causing the lever *a b* to lower its end *a*, and to dip into the mercury cup. The local battery B, which has to excite the electro-magnet E, has now a closed circuit. The magnet E, which is in this circuit, attracts its armature, and the pin s is made to strike against the bell G. This transmission apparatus causes a powerful effect of the magnet E, even when only a weak current arrives at the station.

The first experiment with this five-needle apparatus was made at the North-Western station with a wire of 1¼ miles. In 1840 the Great Western Company constructed a line 39 miles long, but did not extend the line any further on account of the expense.

The first pointer telegraph which worked well was that invented by Wheatstone in 1839, which is represented in Fig. 752. The sign-giver here consists of

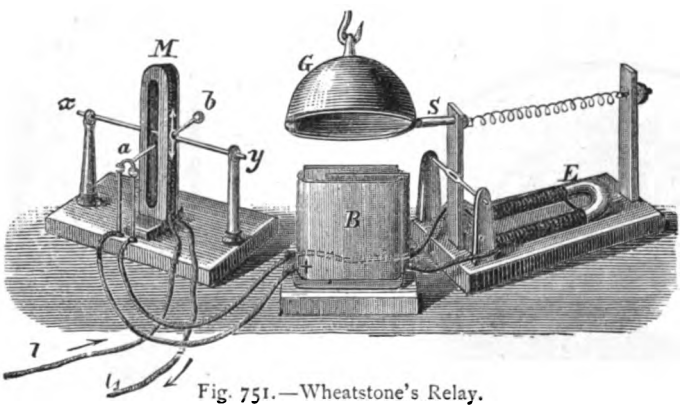


Fig. 751.—Wheatstone's Relay.

a ratchet wheel K. The springs *n n'* are so arranged that when one spring makes contact with a tooth, the other spring will stand between two teeth. The negative pole of the battery is connected with the metal mass of the wheel, and the current flows from the positive pole to the receiving station. The receiving apparatus consists of the two electro-magnets *e e*, with the two armatures *a a'* and the clockwork *u*, whose pointer *z* moves over the different signs, the clockwork being put in motion by the weight G. The wire + *l* of the sending station leads to the clamp K of the receiving station; clamps K_1 and K_2 of the receiving station are connected with the springs *n n'*; when the wheel K is moved the battery current will alternately flow through the electro-magnets *e* and e_1, passing through the electro-magnet *e* when the spring *n* rests upon a tooth, as shown in the figure, and through the electro-magnet e_1 when the spring *n'* comes to rest upon a tooth. Owing to the alternate excitement of the two electro-magnets, an alternate attraction of the armatures *a a'* will take place, and, therefore, a swinging backward and forward of the escapement.

Of all the many forms of telegraph apparatus none has been more ex-

tensively employed than the one devised by Morse; but although he has done much for telegraphy, the actual invention of the apparatus that bears his name was probably suggested to him by experiments made by others; this may be proved by the following sketch of Morse's labours and life, taken from J. Hamel's *Entstehung der Galvanischen und Elektromagnetischen Telegraphie*:— Samuel Finley Breese Morse was born in 1791, at Charleston, where, until he reached the age of forty, he devoted his time to painting. He visited Europe twice, in 1811—1815, and in 1829—1832. On his return voyage to America he made the acquaintance of Professor Charles V. Jackson, of Boston, and on board ship Morse saw Jackson's experiments in electricity, which

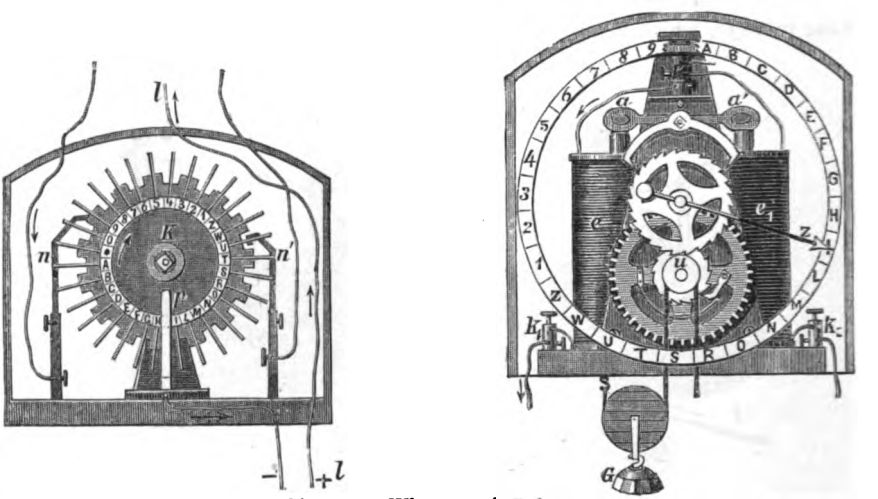


Fig. 752.—Wheatstone's Pointer.

suggested to him the possibility of using electricity for signalling. When he returned to America, Morse again for a time devoted himself to painting. In November, 1835, he resumed his telegraphic experiments, but obtained no results of any value because of his lack of knowledge of the subject. In 1836 he received several hints from a professor of chemistry, Leonard Gale, who afterwards became Morse's partner.

In 1837 an apparatus was constructed which made the electric transmission of signs by combinations of two simple motions possible, nine signs being used to represent the figures 1—9. Fig. 753 represents Morse's apparatus for the transmission of these nine numbers. The frame *c c* is vertically fastened upon a table, and carries a kind of pendulum *o* B and the electro-magnet E. Upon the pendulum is fastened the armature of the electro-magnet, which bears a pencil at the lower end; a paper strip passes over the roller R underneath the pencil, and is kept in motion by means of the clockwork *h* and the rollers *r r'*. When the pendulum is in its normal position the pencil traces

lines upon the paper that are parallel in direction to the length of the strip; when the armature is attracted a slanting line is traced by the pencil, and another slanting line is traced when the magnet lets the armature go, and the pendulum returns to its original position. By alternate magnetisation and

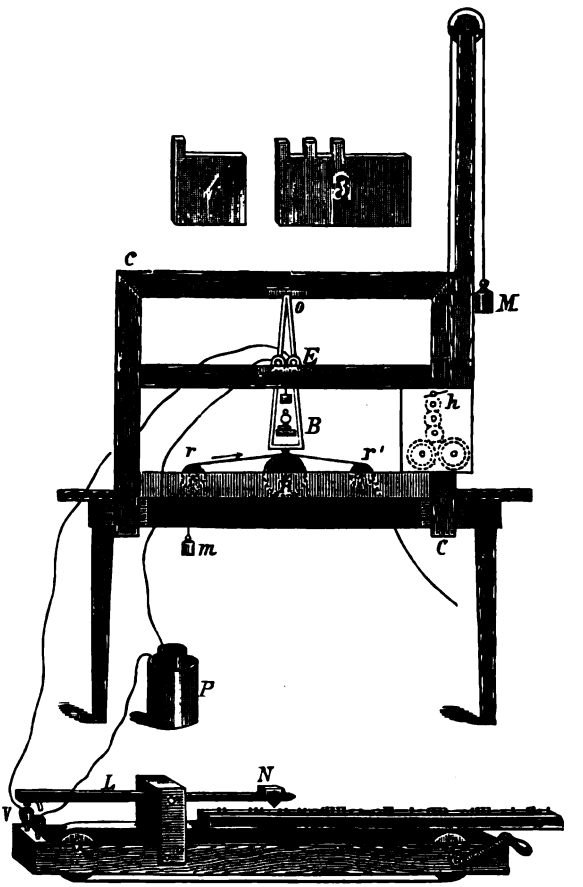


Fig. 753.—Morse's First Telegraph.

demagnetisation V-shaped lines are formed. One V indicates the figure 1; two V's the figure 2; and so on. These deflections of the pencil are produced in the following manner: The lever L of the sign-giver has the weight N placed at one end, and under this a pin; at the other end a bent wire is arranged, which, when dipping into the mercury cups V, connects them with each other, and by doing so closes the circuit of the battery P and electro-magnet E. The types are placed in the wooden frame A. When A is made to move under the

lever N, the lever will close the circuit as often as the edges of the lead types raise the lever-end N. The pencil at B will, therefore, make corresponding signs on the paper strip. About the time when this apparatus was constructed, Morse made the acquaintance of Alfred Bail, who aided him greatly, and afterwards became one of Morse's partners. The experiment succeeded for the first time on the 4th September, 1837. The signs obtained were those shown in Fig. 754, which correspond to the numbers, 215, 36, 2, 58, 110, 04, and 01837, which, according to the telegraphic dictionary, gave the words, "Successful attempt with telegraph, September 4, 1837." Morse's apparatus became known to Francis O. T. Smith, a member of Congress, and through his aid Morse was enabled to make a journey to London and Paris, which, however, proved fruitless as regards the finding of means to give effect to his invention. When he returned to New York (1839) Morse again took to painting, and afterwards to Daguerreotyping, in order to maintain himself. In 1843 Congress voted the sum of 30,000 dollars for the construction of a trial

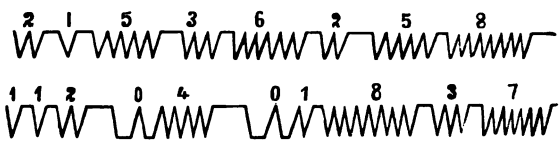


Fig. 754.—Morse's Writing.

line, and, as a consequence of this grant, the first line in America of 40 miles was tried for the first time in 1844, between Washington and Baltimore.

Morse's apparatus had, meanwhile, undergone many modifications, so that by this date it closely resembled the form now usually employed. From that period the Morse apparatus had a large demand, and in a very short time became widely if not generally used. Morse became electrician of the New York and Newfoundland Telegraph Company, and also of the New York, Newfoundland, and London Telegraph Company, and about the same time he was further appointed Professor of Natural History at Yale College, New Haven. In 1857 he received a present from ten European States of 400,000 francs, as an acknowledgment of his international services. Two monuments were erected to him in New York—one in 1871, the other in 1872, the year of his death.

The Morse instrument, which has been greatly improved in Europe, is equalled if not surpassed in usefulness by Hughes' printing instrument. This and the Morse apparatus have been declared by the International Telegraph Congress to be the only exclusively reliable instruments for the international telegraph service. The first printing telegraph instrument, however, was constructed by the American, Bail, in 1837. Bain followed in 1840, and Wheatstone in 1841. David Edwin Hughes was born in London, in 1831, but emigrated with his father to Virginia in 1838, where he was appointed Professor of

Music at the High School, Barnstown. Here he studied natural science with such success that after some time the professorship was offered to him. He devoted his time for some years to the construction of a type-printing telegraph apparatus, which he completed in 1853. A society in New York was formed, which undertook the introduction of the printing apparatus in America, whilst Hughes himself went to Europe for the purpose of making his instrument known. He met with no success in England, but was able to introduce the instrument into France, whence it very soon reached other countries. The chemical telegraph, which had been first constructed by Sömmerring, was so much improved in the course of a few years that it was of practical use to Bain in 1842. The principle consists in causing the end of the wire of the receiving station to move over a paper soaked in a solution that will be decomposed when a current flows through the wire, and regulating the flow of current from the sending station, so that the

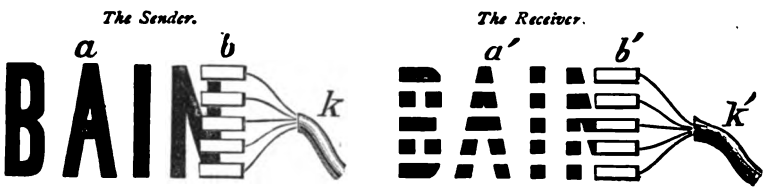


Fig. 755.—Bain's Chemical Telegraph.

decomposition and consequent colouring of the paper appear as written or printed letters. The word to be telegraphed is compounded of large simple metal letters, as shown in Fig. 755; these are connected with the positive pole of a battery, the negative pole of which reaches the earth. A metal plate, which is connected to earth, and upon which the paper containing the salt solution to be decomposed is laid, is arranged at the receiving station. The brush *b* at the sending station, which consists of five metal springs, is connected by means of the cable K K′ with a similar brush *b′* at the receiving station, so that the first spring of *b* is connected with the first spring *b′*, and so on. If the brush *b* is moved over the metal letters, and the brush *b′* is moved at the same time and with the same velocity over the prepared paper on the metal plate, a circuit is closed as often as a spring of the brush *b* comes in contact with the metal letters, and consequently a current flows through the springs of the two brushes, which decomposes the salt solution and leaves a visible mark. For this purpose potassium iodide in starch may be taken. The iodine is separated out by the current, and turns the starch blue or violet, in which colour the letters appear. The chemical telegraph has been modified by Stöhrer, Siemens, Gintl, and others. The copying telegraph by Bakewell and Bonelli, as well as the pantelegraph by Caselli (1856), may be classed among these.

After it had been found out that instead of using several wires one sufficed,

it was thought possible still further to utilise this one wire; this led to the discovery of duplex telegraphy and multiplex telegraphy. We owe the invention of the duplex system and the first practical experiments concerning it to Professor F. A. Petrina and to the late director of the Austrian Telegraph Service, William Gintl (born 1804, died 1883). An apparatus constructed by Gintl was used in these experiments, because the Morse apparatus offered difficulties. In 1854, Frischen, in Hanover, and Siemens, independently of each other, invented duplex methods. Maron gave a method based on the principle of Wheatstone's bridge in 1863. A number of other proposals were made, to which no attention was paid until the American Stearns published his duplex apparatus. By a duplex method of sending on telegraphic lines is meant the transmission of telegraphic signs in opposite directions simultaneously along one and the same wire. Multiplex telegraphy has for its object the better utilisation of one wire, so that several operators may send currents through one and the same wire. If, for instance, with a single system, eight signs can be given in one second, by eight currents passing during that time through the leads; with a multiplex arrangement, in one second one hundred and more currents may be sent through the leads, which proves that the wire is only partly utilised when worked with the single system. Newton gave a method for the better utilisation of the wires as early as 1851, and Rouvier, Hughes, and others followed Newton's plan more or less closely. Duplex systems for Morse writing have been recently devised by B. Meyer and A. E. Granfield; multiplex systems for the Hughes apparatus, by Baudot and Schäffler.

Cable Telegraphy.—Before we close our short sketch of the historical development of telegraphy, we may make a few remarks regarding the development of cable telegraphy. As early as 1774, when it was proposed to employ frictional electricity for telegraphical purposes, Le Sage, in Geneva, suggested the construction of a conducting cable; for this purpose glazed earthenware tubes were to be furnished with partitions of the same material, having holes through which the wires were to be taken. The telegraph apparatus consisted of double pith ball pendulums for each letter. In 1809, Sömmerring covered the wire with a solution of caoutchouc, in order to convey it unhurt through water. In 1812 Schilling succeeded in exploding powder-mines by means of insulated wires which led across the Neva. Shortly before his death he made preparations to connect Cronstadt with Peterhof, by means of a cable, which was intended to be sunk in the Gulf of Finland. Jacobi, in Petersburg, in 1842, used a specially prepared wire, which was enclosed in glass-tubing, and then embedded in fine sand. With the introduction of gutta-percha, in 1843, a new era commenced for the construction of cables. Siemens used gutta-percha insulation for the first trial line. The new insulating material seemed to do good service, and Prussia, Austria, and Russia at once used it for their under-ground leads; the insulation of the leads, however, went from bad to worse, so that the Prussian Telegraph Direction in 1852 was forced to discontinue using it. In 1840

Wheatstone proposed to connect France with England by means of a cable. In 1842 Morse made successful experiments in the haven of New York, and also warmly advocated the cable connection of America with Europe. In 1845 Ezra Cornell succeeded in connecting Fort Lee with New York (a distance of twelve English miles), by means of a cable which was laid in the Hudson; this cable did good service till 1846, when it was destroyed by the ice. In 1850, Dover and Cape Grisnez were connected by means of a cable, which lost its insulation the day after it had been laid by its friction against the rocks. The cable laid in 1857, by the Submarine Telegraph Company, between Dover and Calais, was protected by a cover of iron wire, and remained in use until 1875. The first attempts to connect England with Ireland were made in 1852. After failing twice, a cable was laid between Cagliari and Bona in 1860.

The Atlantic Cable.—Cyrus Field had meanwhile established a company in America (in 1854), which had obtained the right of landing cables in Newfoundland for fifty years. Soundings were made in 1856 between Ireland and Newfoundland, showing a maximum depth of 4,400 metres. Having succeeded, after several attempts, in laying a cable between Nova Scotia and Newfoundland, Field founded the Atlantic Telegraph Company in England, which decided to make use of a cable such as that shown in Fig. 756. Each of the six copper wires in the centre had a diameter of 0.76 millimetres, and was covered by three layers of gutta-percha; these were enclosed in a covering of tarred jute, and the whole was covered by eighteen cables, each consisting of seven iron wires. The length of the whole cable was 4,000 kilometres. and was carried by the two ships *Agamemnon* and *Niagara*. The distance between the two stations on the coasts was 2,640 kilometres. The laying of the cable commenced on the 7th of August, 1857, at Valentia (Ireland); on the third day the cable broke at a depth of 3,660 metres, and the expedition had to return. A second expedition was sent in 1858; the two ships met each other half-way, the ends of the cable were joined, and the lowering of it commenced in both directions; 149 kilometres were thus lowered, when a fault in the cable was discovered. It had, therefore, to be brought on board again, and was broken during the process. After it had been repaired, and when 476 kilometres had been already laid, another fault was discovered, which caused another breakage; this time it was impossible to repair it, and the expedition was again unsuccessful, and had to return. In spite of the repeated failures, two ships were again sent out in the same year, and this time one end of the cable was landed in Ireland, and the other at Newfoundland. The length of the sunk cable was 3,745 kilometres. Field's first telegram was sent on the 7th of August, from America to Ireland. The insulation of the cable, however, became more

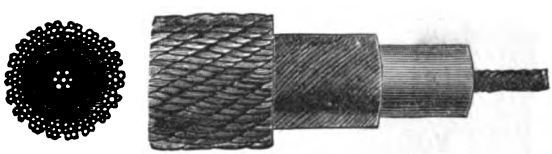


Fig. 756.—The First Atlantic Cable.

defective every day, and failed altogether on the 1st of September. From the experience obtained, it was concluded that it was possible to lay a trans-Atlantic cable, and the company, after consulting a number of professional men, again set to work. Of the samples sent in by the different makers, that of the firm of Glass, Elliott, and Company was considered likely to answer the purpose best, and an order was given for 4,266 kilometres. Fig. 757 shows the different parts of the cable, viz. a copper strand of seven wires, a gutta-percha envelope consisting of four layers, a cover of tarred hemp, and an outer coating of iron wires covered with hemp. The *Great Eastern* was employed in laying this cable. This ship, which is 211 metres long, 25 metres broad, and 16 metres in height, carried a crew of 500 men, of which 120 were electricians and engineers, 179 mechanics and stokers, and 115 sailors. The management of all affairs relating to the laying of the cable was entrusted to Canning. The coast cable was laid on the 21st of July, and the end of it was connected with the Atlantic cable on the 23rd. After 1,326 kilometres of cable had been laid, a fault was discovered, an iron wire was found stuck right across the cable, and Canning considered the mischief to have been done with a malevolent purpose. On the 2nd of August, 2,196 kilometres of cable were sunk, when another fault was discovered. While the cable was being repaired it broke, and attempts to recover it at the time were all unsuccessful; in consequence of this the *Great Eastern* had to return without having completed the task.

Fig. 757.—The Second Atlantic Cable.

A new company, the Anglo-American Telegraph Company, was formed in 1866, and at once entrusted Messrs. Glass, Elliott, and Company with the construction of a new cable of 3,000 kilometres. Different arrangements were made for the outer envelope of the cable, and the *Great Eastern* was once more equipped to give effect to the experiments which had just been made. The new expedition was not only to lay a new cable, but also to take up the end of the old one, and join it to a new piece, and thus obtain a second telegraph line. The sinking again commenced in Ireland on the 13th of July, 1866, and it was finished on the 27th. On the 4th of August, 1866, the Trans-Atlantic Telegraph Line was declared open.

Since then other Atlantic cables have been laid, and the great ocean is now spanned by no fewer than nine such links of communication, the last of which was successfully deposited in 1882. A steamer specially constructed is now

employed, as far less expensive than the *Great Eastern*, and the laying of the last cable occupied no more than twelve days, without the slightest hitch or interruption from beginning to end. The later cables do not differ in general construction from those described above; but improvements in details have produced greater strength, and better insulation and conductivity. There is now no practical limit to the length of cable which could be laid if required, beyond the contingencies of severe weather.

MODERN TELEGRAPHY.

The above historical outline will enable us to classify the various systems that are at present in use for the transmission of telegraphic signals. These signals are of two kinds, *visible* and *audible*. Visible signals are either *permanent* or *transient*, according as they are produced by *recording* or *non-recording* instruments. Thus we have—

Non-recording Instruments ... I. Needle Instruments.
II. Sounding Instruments.
(1) The Sounder.
(2) The Bell.
III. Dial Instruments.

Recording Instruments ... IV. Bain's Chemical Marking Instrument.
V. Morse's Instruments.
(1) The Embosser.
(2) The Ink-writer.
VI. Type-printers.

I. NEEDLE INSTRUMENTS.

The needle is a pointer capable of receiving two distinct motions, the one to the right and back, and the other to the left and back; its position, when it is at rest, being vertical. In the earliest needle system there were, as we have seen, as many as twenty-six needles. In Cooke and Wheatstone's instruments there were five needles. The number was reduced to two, and finally, in the latest use of the system, to one. Combinations of the two swings of the needle spell out the alphabet just as, when recording instruments are used, the combinations of long and short strokes form all the necessary signals. A single motion to the left forms the letter *e*, and one to the right the letter *t*. By writing *l* for a nod of the needle to the left, and *r* for a nod to the right, the alphabet will appear as follows:

A lr	H llll	O rrr	V lllr
B rlll	I ll	P lrrl	W lrr
C rlrl	J lrrr	Q rrlr	X rllr
D rll	K rlr	R lrl	Y rlrr
E l	L lrll	S lll	Z rrll
F llrl	M rr	T r	
G rrl	N rl	U llr	

Needle instruments are of two kinds, named from the keys or commutators attached to them, the *drop-handle* and the *tapper*. The drop-handle is simply a commutator worked by a handle (Fig. 758), so that a motion of the handle to the left connects the copper pole of the battery with the line-wire and puts the zinc pole to earth, and a motion to the right connects the zinc pole with the line-wire and puts the copper pole to earth. The receiving instrument is so connected that the former motion of the handle produces a nod of the needle to the left, and the latter a nod to the right.

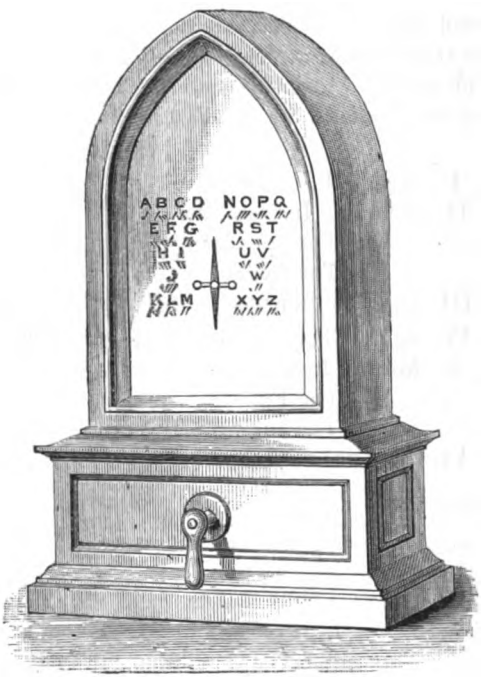


Fig. 758.—Single Needle Instrument.

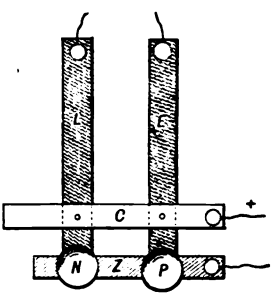


Fig. 759.—The Tapper.

The tapper consists of two bars of brass or copper Z and C (Fig. 759) connected with the battery, and two metal springs L and E, one of which L is connected with the line, and the other E is put to "earth." The springs both pass under C and over Z, and when not pressed on they both touch the bar C, but do not touch the bar Z. One spring must be pressed down to make the circuit. When the finger is pressed upon the knob N of the spring L, it connects L and Z and sends the current from zinc to the line, and from E back to C. If the knob P on E is pressed down, the current goes from zinc to "earth," and from the line back to C. To depress N causes the needle of the receiving instrument to nod to the left, to depress P causes the needle to nod to the right.

II. SOUNDING INSTRUMENTS.

The signals given by the sounding instruments are, like those of the needle, transient, and the instruments are non-recording. They appeal, however, to the ear instead of to the eye. There are two kinds of sounding instruments, the *sounder* and the *bell*. The clerk in charge of a needle instrument has often been known to recognise by the ear when the needle strikes the pin or stop on the left, and when it strikes the stop on the right, and so to be able to write down the message without looking at the instrument. In this case, even the needle instrument may be said to act as a sounder. The simple *sounder*, however, is but an electro-magnet with an armature in the form of a lever, like the instrument represented in Fig. 778. The end of this lever moves between two stops, one of which it strikes when attracted, and the other when released. The time elapsing between the two sounds is short or long, the short corresponding to a nod to the left in the needle, or to a dot in Morse's system, and a long interval to the nod to the right, or to the dash. The sounder has been introduced into America, and has there supplanted all other forms of apparatus. It is also almost universally employed in India.

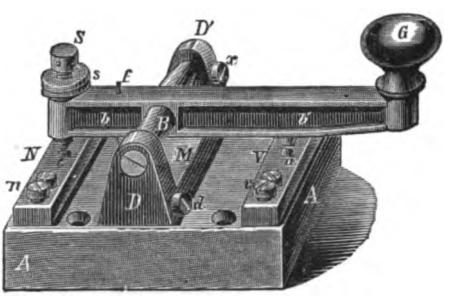


Fig. 760.—The Morse Key.

The earliest form of acoustic instrument used in England was probably Bright's bell. In this instrument two bells of different tone are used, the hammer of one being actuated by currents in one direction, and that of the other by currents in the other direction. The sound of one bell corresponds to dots, and that of the other bell to dashes. The sending apparatus is the same as the tapper of the single needle, and relays and local currents are often needed. The instrument is probably the quickest non-recording instrument extant, but it is complicated in its construction and difficult in its adjustment compared with the sounders. Other bells will be described under the head of special signalling apparatus.

The key required for the sounder is the single Morse key, represented in Fig. 760. Three brass bars N M and V are fastened upon a basement block of wood A; M has the two brass cheeks D D arranged upon it, as chairs or bearings for the support of the axis B. The lever *b b'* moves about this axis, moving in the one direction by the hand of the operator pressing on the knob G, and returning when released in consequence of the tension of a spring *f*; and steel or platinum contacts *c a* are screwed into the bars N and V, the corresponding contact-pins of which pass through the lever *b b'*. One end of the spiral spring is attached to the lever at *b*, and the second end is fastened to the bar M.

This spring serves to hold the lever down upon the contact *c*, which is regulated by the screws s *s*. The line-wire is connected with the middle plate M, the receiving apparatus with N, and the sending apparatus, including the home battery, with V. Hence the key is always set ready to receive a message, but must be pressed down to send one.

III. DIAL INSTRUMENTS.

Wheatstone's A B C System.—The indicating instrument in this system has the letters of the alphabet arranged on a dial, and a pointer is placed in succession opposite the letters that spell out the message. The currents are produced on the principle of a magneto-electric machine turned by means of a handle, which also causes the rotation of the pointer over the face of the dial. There is a key opposite each mark on the dial, and an endless chain passes inside all the keys, passing over a number of small pulleys. When the handle is turned the pointer receives four impulses for each revolution, and moves over four spaces. If, however, a key is depressed the pointer is arrested when it comes opposite to it, and at the same time the current, instead of going to the line, is cut off. When the key is raised again, supposing the handle to be continuously turned, the pointer resumes its course until another key is depressed. Now the dial of the receiver is exactly like that of the sender, and the motion of its pointer is regulated by an escapement wheel propelled by an electro-magnet. The escapement wheel has fifteen teeth, and a complete revolution of the handle of the sender carries it to move two teeth forward, so that the pointer moves over four letters like the pointer of the sender. Hence, the pointers of two stations properly connected and having instruments properly adjusted move synchronously. To secure that both pointers start from the zero point of their dials, the keys of these points are kept depressed. The system works well for private stations.

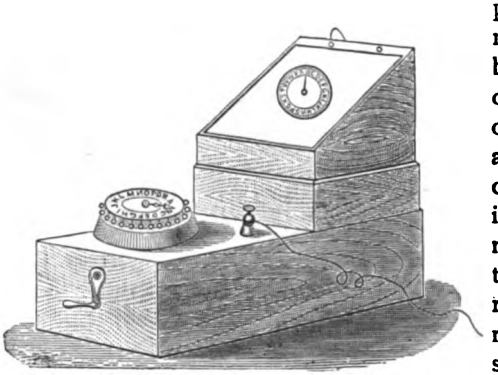


Fig. 761.—Wheatstone's A B C Apparatus.

Bréguet's Dial Telegraph.—In the apparatus just described no battery is employed, but the current is furnished by magneto-electric induction in the act of manipulation. Of A B C systems, where a battery is employed to furnish the current, Bréguet's Dial Telegraph is a good example, and is illustrated in Figs. 762—5. The transmitting and receiving instruments are distinct and different. The transmitting apparatus is shown in Fig. 762. It has a dial. round

the face of which are placed the letters of the alphabet, and the sign +, which is used to divide words; and in another row are placed numerals, as far as 25. A small notch will be seen cut in the rim opposite each letter. A handle M is pivoted to the centre, the arm having a slot cut in it, and this is turned round (in one uniform direction only, never backward) till the letter or figure required appears through the slot, a small pin on the under side catching in the notch, and keeping the position exact. If the letter is overshot the arm must not be moved back, but carried round again; hence the need of the slot and pin, not otherwise material. The removed part of the dial shows a wheel beneath

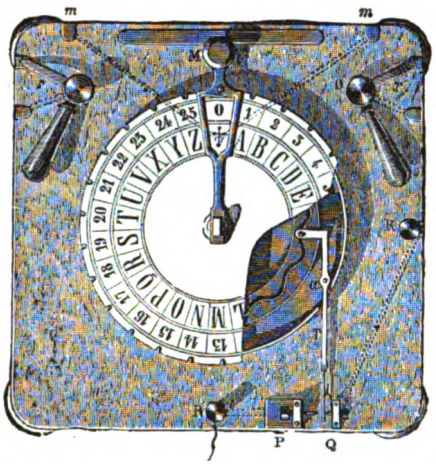


Fig. 762.—Bréguet's Transmitter.

which turns with the handle, and has cut in it a waved groove, having half the number of waves that there are letters, so providing either a crest or a hollow for each. A roller on the end of the bent lever T works in this groove, so that in turning the handle one revolution, the lower end of T is moved from side to side twenty-six times, or thirteen to-and-fro complete motions. At the bottom of the lever a platinum spring thus comes alternately into contact with the contact-screws P and Q. P goes to the line-wire, while the battery-wire goes to *m*, passing thence to the grooved wheel, and so to the lever T.

The receiving apparatus is shown in Figs. 763—5. Fig. 763 is the face, showing a small key-axis between the numbers 25 and 1 on the dial, by which the clockwork in the interior is wound up. Fig. 764 is a back view, showing interior parts, except that the magnet, which faces the dotted circles of the armature A, is removed for clearness. The clockwork causes the pointer to travel round the face rather quickly until stopped or regulated by the escape-wheel D, a larger view of which is given in

Fig. 765. It comprises two ordinary notched wheels mounted on one axis, so that the teeth alternate. The pallet *i* underneath, as it vibrates backwards and forwards, alternately catches the tooth of each wheel in succession, so that if

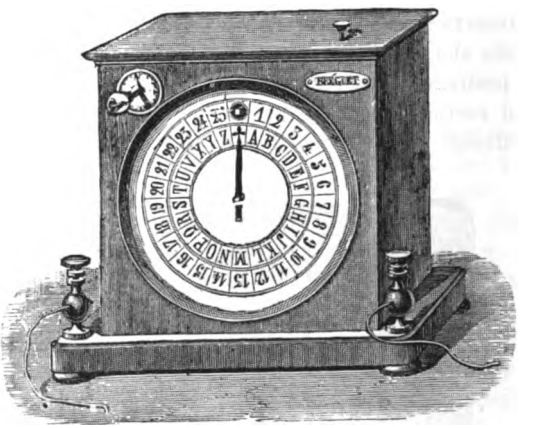


Fig. 763.—Receiving Instrument.

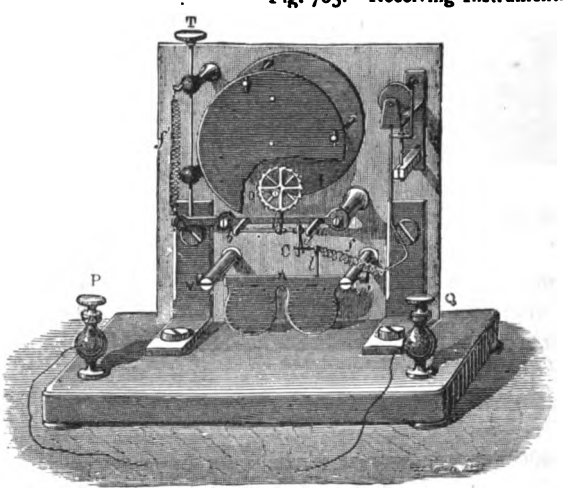


Fig. 764.—Construction of Receiver.

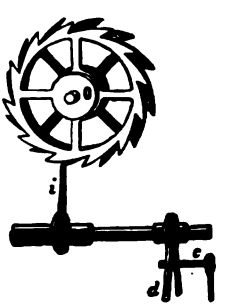


Fig. 765.—Escape-Wheel.

there are thirteen teeth on each, every movement of the pallet enables the wheel to revolve one twenty-sixth of a revolution. The pointer is fixed to the axis of this wheel, so that in the same period it also moves forward the space of one letter. The armature A (Fig. 764) swings to and from the observer from suspending pivots fixed in the projecting supports v v′, and carries with it the arm *l*, having a horizontal pin c projecting from one end of it. A spiral spring *f* draws

the armature back when the current does not pass through the coils of a horse-shoe electro-magnet, whose poles are opposite A. The armature, and with it the pin C, therefore swing backwards and forwards as current is made and broken; and in the enlarged view of the escape-wheel in Fig. 765, it will be seen how this motion of the pin *c* in the fork *d* works the escapement, thus causing the pointer to move round the dial one step for every "make" or "break" of current.

The action of the two instruments can now be readily understood. It has been seen that a complete revolution of the pointer of the sending instrument makes and breaks current thirteen times, or makes twenty-six changes; and these twenty-six changes also move round the pointer of the receiving instrument a complete revolution. Any lesser number of steps is similarly reproduced in the receiving instrument.

This instrument works in practice remarkably well. Occasionally the pointer will get wrong, owing to mistake or interruption in the message; in that case the head of the rod T is depressed, which liberates the escapement altogether until it has rotated back to the sign +, when all starts correctly again. The handles near the top of the instruments direct the current to a signal-bell on the receiver at pleasure.

IV. CHEMICAL MARKING INSTRUMENTS.

Bain's invention for signalling by means of the electrolytic effects of a current has already been described. It was at one time the only recording instrument used in England, but it has been gradually supplanted by the Morse. As, however, it registers its messages with great rapidity, the demand for speed may lead to its restoration to favour. We have but two additions to make to the description already given, first to point out the importance of attending to the order of the connections, and secondly, to give the composition of suitable solutions. If the sending key be of the kind shown in Fig. 760, the wire from the copper pole of the battery must be brought to the front bar V. If the current be sent in the opposite direction, no mark will be made by the printer. The *starch solution*, already mentioned, consists of one part of potassic iodide with twenty parts of starch, diluted by forty parts of water. The *prussiate of potash solution*, which is commonly used, consists of one part (by measure) of prussiate of potash (potassic ferrocyanide), one part of ammoniac nitrate (a saturated solution), and two parts of water. The effect of the ammoniac nitrate is to keep the paper from drying.

V. THE MORSE SYSTEM.

(1) **Embossers.**—The Morse apparatus consists of an electro-magnet and a printing arrangement, which is furnished with wheelwork, and a disc with telegraph paper. The electro-magnet E E (Fig. 766) consists of two cylindrical cores of very soft wrought iron, which are connected at their lower ends by an iron plate, so that they form a horse-shoe magnet. Both arms have a great number of turns of insulated copper wire round them,

and are connected in such a manner with the source of electricity and with each other, that the magnet has a north pole and a south pole at its upper ends. The armature *a* of the electro-magnet, and the pencil s, are fastened to the lever *h*, which can move about a horizontal axis. The lever is connected with a spiral spring, attached to a screw *b*, which when turned in the right direction increases or diminishes the tension of the spring, and therefore offers a greater or lesser resistance to the attraction of the armature by

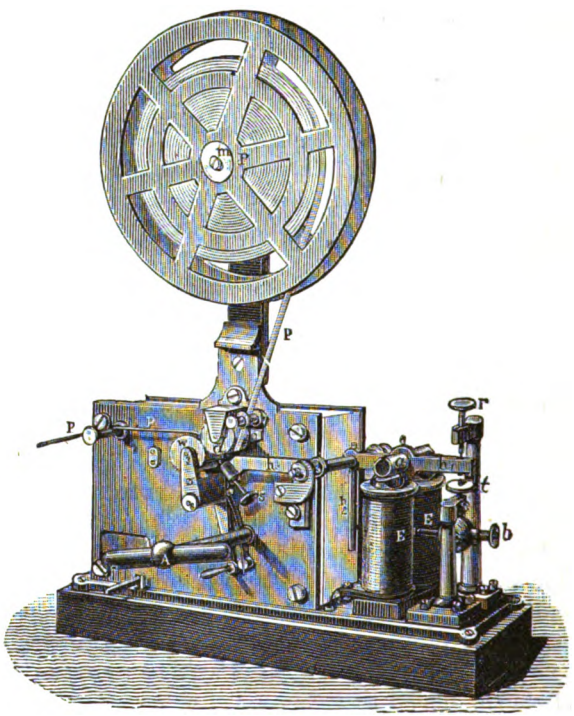


Fig. 766.—The Morse Embossing Instrument.

the magnet. The play of the lever is limited by the contact-screws *r* and *t*. The printing arrangement by which the signals are impressed on the strip of paper drawn off the wheel may be better understood from Fig. 767. In both figures the various parts are indicated by the same letters. The end of the lever *h* is split, and the pencil s is placed in this slit. This pencil is adjusted by means of the knob s_1, and ends in a blunt but glass-hard point, which serves the purpose of marking the paper. When the pencil is arranged in the right position, it is maintained in it by tightening the screw *n*; *d* is the printing roller, which turns round the axis a_2, and has a groove at r

in order to facilitate the marking of the pencil. The paper is held between the rollers *d* and *w*, and the pressure of *d* upon *w* is regulated by means of the spring *q q*, one end of which is fastened to the axis *p* of the brass piece *b*, so that the spring presses against the metal piece K; the second end of the spring presses against the screw *x*, and thus the pressure can be regulated by turning the screw; *r r* are metal pieces, which can slide along K, and serve as guiding pieces for the paper; *y y* are screws which keep the guiding pieces in the required position. To prevent the screws *y y* from slipping, the bolt *i* is placed across them. As often as a current is sent through the electro-magnet E E, the latter attracts its armature, and the lever *h h* makes contact at *h*; as often as this happens, the pencil makes a mark on the paper at *d*. When the current lasts

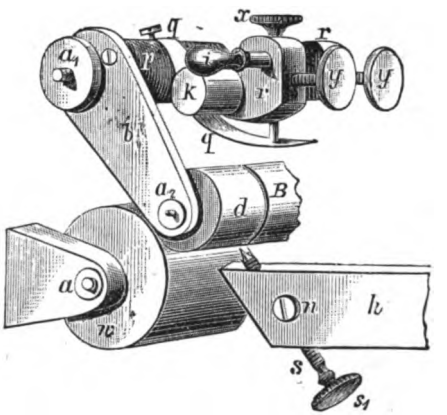


Fig. 767.—The Morse Writer.

only a short time, a short line, technically called a dot, is produced; when the current lasts a longer time, a dash is produced.

The Morse Alphabet.—Combinations of dots and dashes give the different letters, numbers, and signs, and thus form the Morse alphabet:—

a . —	l . — . .	v . . . —	6 — . . . .
b — . . .	m — —	w . — —	7 — — . . .
c — . — .	n — .	x — . . —	8 — — — . .
d — . .	o — — —	y — . — —	9 — — — — .
e .	p . — — .	z — — . .	0 — — — — —
f . . — .	q — — . —	1 . — — — —	. . . . .
g — — .	r . — .	2 . . — — —	? . . — — . .
h	s . . .	3 . . . — —	, . — . — . —
i . .	t —	4 . . . . —	: — — — . . .
k — . —	u . . —	5	! — — . . — —

The letters thus formed of dots and dashes are separated by variable spaces as they are called. There are three kinds of spaces: the space separating the

elements of a letter, that separating the letters of a word, and that separating the words themselves. These durations of break or silence are as necessary as the durations of contact or sound. When we look upon the Morse alphabet as applicable to the various instruments described, including the sounder, we may define it as a method by which time is divided into multiples of an arbitrary standard or unit, viz. the dot.

1. A dash is equal to three dots.
2. The space between the elements of a letter is equal to one dot.
3. The space between the letters of a word is equal to three dots.
4. The space between two words is equal to six dots.

The following arrangement of the signs will assist the memory to retain them. The foundations of the alphabet are the dot (.) representing the letter e, and the dash (—) representing the letter t. This gives us the group e and t of the first order. Placing a dot before each of these elementary characters, we have

. .	i	. —	a

Placing a dash before each elementary signal we have

— .	n	— —	m

These give us the group of the second order, i, a; and n, m.

Now affixing to each of the above four signals first a dot and then a dash, we have

. . .	s	— . .	d
. . —	u	— . —	k
. — .	r	— — .	g
. — —	w	— — —	o

These constitute the group of the third order, s, u, r, w; and d, k, g, o.

Pursuing the same plan with these eight characters, we have

. . . .	h	— . . .	b
. . . —	v	— . . —	x
. . — .	f	— . — .	c
. . — —	ü (German)	— . — —	y
. — . .	l	— — . .	z
. — . —	ä (German)	— — . —	q
. — — .	p	— — — .	ö (German).
. — — —	j	— — — —	ch

These constitute the group of the fourth order, h, v, f, ü, l, ä, p, j; and b, x, c, y, z, q, ö, ch.

There is also the French accented é (. . — . .), but with this exception no letter exceeds four signals. Combinations of five signals are employed to represent the numerals and cypher.

The stops and other signs of punctuation are made by a combination of six signals.

(2) **Ink Writers.**—Thomas John, an Austrian engineer, constructed an ink writer for use at the central station of Vienna, in 1854, which was patented

in Paris, and his modification of the Morse apparatus was then adopted by Digney and Company. Lewert and Siemens also constructed ink writers. Digney's ink writer, which is largely used in France, is shown in Fig. 768. It is similar in construction to the apparatus just described, except that for the style is substituted a small metallic disc, which revolves in ink. The electro-magnet E is in all respects the same as that of the embosser, except that its resistance is considerably greater. The lever $h\,h_1$, however, is differently

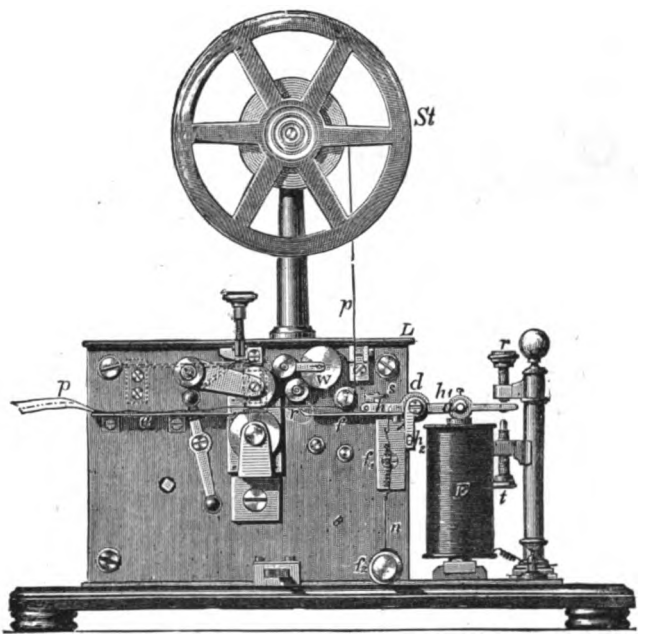


Fig. 768.—Digney's Ink Writer.

constructed. At *a* it has an armature of a cylindrical shape, consisting of soft iron, which is slit open at its upper end; at *h* it has the spring *f*, and its axis of rotation *d* rests upon the piece h_2. The screws *r* and *t* limit the motion of the lever. The effect of the electro-magnet on the armature is regulated by the spiral spring f_1, which is connected by means of a string to the regulation screw f_2. Opposite the slightly bent end of the spring f_1 is the printing disc *r*, which comes in contact with the printing roller *w*. The strip of paper *p* is taken over the roller *i*, and passes between the printing disc *r* and the spring f_1. The position of the spring as regards the disc can be regulated by means of a screw. When a current passes through the electro-magnet E the latter attracts its armature *a*, lowers h_1, and by raising *h* the bent end of the spring f_1 presses the strip of paper *p p* against the disc *r*.

The electro-magnet in the ink writer by Lewert is made adjustable to either of two systems, namely, the system with constant current or that with transient current, and the lever consists of two movable portions connected with each other. In order that the need for this arrangement may be clearly understood, it is necessary to give the following explanation: Telegraph lines are worked in two different ways—viz. either with a working current, or with a constant current. In the first case the circuit is without current during certain intervals, and is "made" only when a signal has to be transmitted; in the latter case a current is always flowing through the circuit, and is interrupted at the required moment. If a line is to be worked both ways, the telegraph apparatus will have to be arranged so that the signs are produced in the same form with both

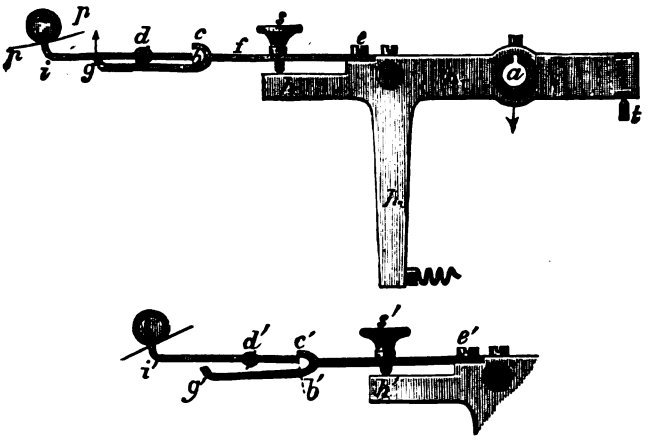


Fig. 769.—Brabender's Lever.

methods. This is the purpose of the above-mentioned lever, which consists of two parts.

Fig. 769 represents a lever by V. Brabender. The spring *f*, which terminates in the prongs *c* and *g*, is fastened to the lever $h\,h_1\,h_2$ by means of a screw *e*. The position of the spring *e f* is regulated by the screw s; *a* is the armature of the electro-magnet. The writing lever proper *i b* is movable about *d*. The principal figure shows the regulation of the spring when a circuit is used, which is without current during certain intervals—that is to say, when not signalling. When the armature *a* is attracted by the electro-magnet it causes h_1 to make contact at *t* (Fig. 768), and the arm of the lever *h* and *f g* to move upwards. As *i d* rests upon *g*, the end of the lever *i* will also be moved upwards—that is, it will press the strip of paper against the printing disc. If, however, the screw *s* is tightened so that the spring *e f* is pressed down upon *h'*, as shown in the second part of the figure, the instrument is prepared to act with constant current broken only for the purpose of signalling. The writing lever, which is movable about

d', will be caught by the prong c', and will lose contact with g'. The arm of the lever d' i' will be lowered, and the strip of paper will cease to make contact with the printing disc when the current is flowing, even though the attraction of the armature a' causes a moving upwards of h' in this case too. When the armature a' is not attracted—that is, when no current flows through the circuit—the lever-

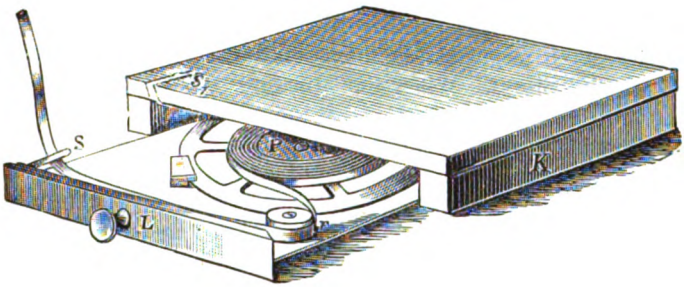


Fig. 770.—The Paper Wheel of the Ink Writer.

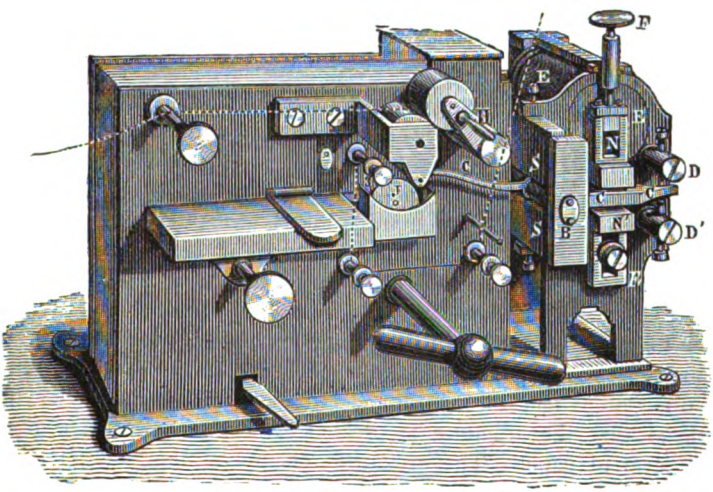


Fig. 771.—The Polarised Ink Writer.

arm h' is lowered, and the prong c' presses the arm d' b' down, and d' i' up, so that the strip of paper is then pressed against the printing disc. To make the apparatus do for either method, it is only required to turn the screw s in the one or the other direction.

In the *normal ink writer* the paper is arranged upon a horizontal wheel, as shown in Fig. 770.

Polarised Ink Writers differ from ordinary ink writers in the construction of their electro-magnets and writing levers. The first apparatus of this kind

was constructed by Siemens, and is shown in Fig. 771. S S are south poles of a permanent magnet, which is connected at its other end with the iron cores of the electro-magnet E E, and gives north magnetism to them as long as the coils remain without current. The adjustable shoes N N′ have north magnetism, therefore, when the apparatus is at rest. One arm of the writing lever C C, which can move about B, consists of soft iron, and represents the armature of the magnet, being placed between these two poles. In consequence of its position it receives south magnetism by induction. The arm of the lever to the left carries the printing disc J. When the armature, whose motion is limited by the contact-screws D D′, is adjusted so that the two north poles affect it equally, it will remain exactly midway between the two poles; but if the slightest alteration is made in the attractive force of either pole, the armature will be moved in the corresponding direction. When a current passes through the coils of the electro-magnet, north magnetism is produced in one of its cores, and south magnetism in the other; but as both poles have north magnetism (for the magnet is permanent) it is evident that north magnetism will be strengthened in one of the cores, whilst either the north magnetism will be partially neutralised or else it will be wholly neutralised, and south magnetism will be produced in the other. The armature will, therefore, move towards the first pole; by this means the sensitiveness of the apparatus is greatly increased.

In order that this apparatus may be used with continuous currents, the shoe N is so arranged by means of the screw F, that it affects the armature more powerfully than the pole N′. The armature, therefore, makes contact at D; if now a current of corresponding direction be sent through the electro-magnet, the north magnetism of N′ will be increased, and the armature will move downward, and make contact at D′, thus pressing the printing disc against the strip of paper, and producing the desired sign. When the current is broken, the attractive force of N′ prevails, and the armature goes back again to D. The polarised ink writer may also be used with alternating currents, by causing the armature to be so arranged that both poles N and N′ affect it equally. When a current of a certain direction is sent through, the electro-magnet N′ is strengthened, and N weakened, so that the armature is pressed against D′, and the printing disc against the strip of paper. The armature remains in this position as long as the same current lasts. When a current is sent through in the opposite direction the apparatus N will be strengthened, and N′ will be weakened, and the armature will move towards D, and the strip of paper will lose contact with the printing disc.

VI. TYPE-PRINTERS.

Hughes' Type-printing Apparatus.—Fig. 772 represents a complete Hughes' type-printing apparatus, in which may be noticed a keyboard, a contact wheel, an electro-magnet, with an armature, connected with a rather complicated system of wheelwork, in front of which are the printing wheel and tape-roller. The messages are printed by this instrument in bold Roman type. The instruments at the sending and receiving stations are identically similar, and a

current of short duration is required for each letter. The type wheels, which have the alphabet on their edges, are kept rotating synchronously. This synchronous movement of the corresponding pieces at the two stations is the principal difficulty of the instrument, and requires very accurate adjustment. There are twenty-eight black and white keys, which, with the exception of the first and fifth, counted from the left, are marked with letters, signs, and numbers. The contact arrangement D is fastened upon the table, and upon it rests the contact slide C, which rotates about the axis *a*. The contact slide is made by the clockwork to rotate with the same velocity as the printing wheel F, on the edge of which the letters, signs, and numbers are

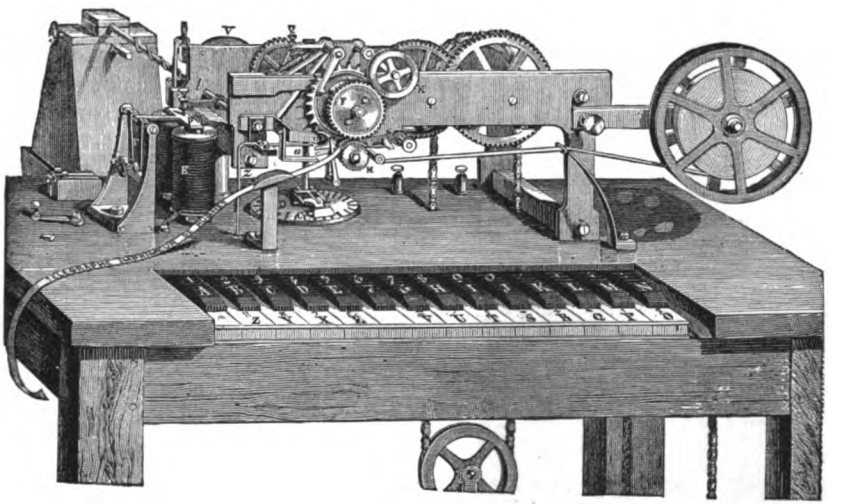


Fig. 772.—Hughes' Type-printing Telegraph.

arranged in relief. The ink-roller K furnishes the wheel with the necessary printing-ink; a regulating wheel behind the type wheel corrects irregularities which might occur in the apparatus. To the left of the wheelwork is the magnet E, which loosens its armature *p*, and lifts the left arm of the lever *l*, when a current of the required direction and strength passes through its coils. The strip of paper is pressed against the lower edge of the type wheel by means of the printing roller M. The heavy fly-wheel V is used in order to make the machine move more regularly.

The receiver and the sender are united in one apparatus, and the receiving and sending stations use instruments that are identical as regards form, in order that the slide and the type wheel may be made to move synchronously at both stations. The mode in which the apparatus works is as follows: When a key is depressed, the lever connected with it raises a pin underneath the disc D; this pin projects from one of the rectangular openings which are made

on the surface of the disc, and separates the two movable portions of which the slide C consists. When connection is made between the line battery and the line a current is sent into the leads, and thence to the apparatus of the receiving station, where it flows into the coils of the electro-magnet. When there is no current the magnet holds the armature *p* attracted; but the arriving current neutralises the magnetism of the electro, and the armature moves up; this affects the lever *l*, which, in its turn, starts the printing arrangement. If, for instance, the key upon which the letter A is printed is depressed at the sending station, a current arrives at the receiving station when the letter A is opposite the printing roller M. The current is only able to flow through the leads to the receiving apparatus at this moment because the

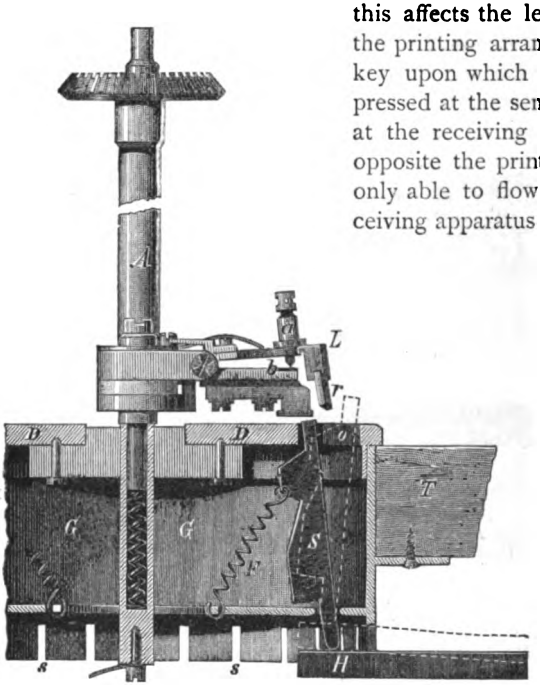


Fig. 773.—Current Arrangement in Hughes' Apparatus.

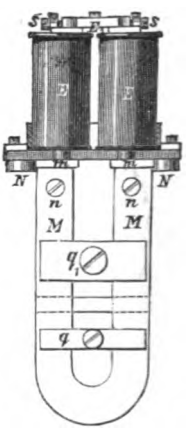


Fig. 774.—The Magnet.

slides move synchronously with the type wheels, and the closing of the circuit can only take place at the moment when the slide moves over the opening of the disc D, which corresponds to key A. When the armature *p* is lifted at the receiving station, it raises the lever, and causes the printing roller M to press the paper strip against the type wheel, and produce the letter A.

We have yet to show more clearly how it is that the current flows only when a particular letter is passing the connection with a particular key. The arrangement of the pin case, and the slide with its contact arrangement, are shown in Fig. 773. D D represents a section of the disc fastened to the table T, and showing one of the rectangular openings *o*, each of which corresponds to a key. The disc D D forms the cover of the case G G, which has slits *s s* cut on its lower side. The levers connected with the different keys project through

these slits. The lower ends of the pins S rest upon the levers, so that their upper ends are inserted into the openings *o* (indicated by the dotted lines) when the key is pressed down. The axis of rotation A of L passes through the centre of the disc D D, and is connected with the wheelwork of the type wheel by means of cog-wheels. When L arrives at an opening *o*, the pin S, which is made to project from *o* by depressing a key, raises *r*, and by this means breaks contact between *a* and *b*. The leads from the battery are so arranged that when L has this position connection is made with the line, and the current flows to the receiving station.

When the current arrives at the station it has to demagnetise the magnet. In order to facilitate this demagnetisation, Hughes constructed a magnet like that shown in Fig. 774. It consisted of a permanent horse-shoe magnet M M, and the electro-magnet E E. The former consisted of four steel plates in horse-shoe form, which were held together by the screws N N, and the brass cross-pieces $q\,q_1$. The cores of the electro-magnet consisted of hollow wrought-iron cylinders, which were placed upon the poles of the permanent magnet; wire was coiled round these hollow cores, and they were then covered at both top and bottom with brass plates, in order to protect the coils. The resistance of the electro-magnet coils is 1,200 Siemens' units. Over the shoes of the magnet is placed the armature E_1. Even when the coils are without current the iron cores possess a certain magnetic force in consequence of their connection with the permanent magnet. The spring affecting the armature is so regulated as to be weaker than the magnetic force of attraction, so that the armature remains on the shoes of the electro-magnet; but when a current of the proper strength flows through the coils the attraction of the magnet is neutralised, and the spring draws the armature off.

The Exchange Telegraph Company's System.—Another special system of telegraphy is that of the Exchange Telegraph Company of London, which disseminates news from a central office to a large number of subscribers (at present about 750) scattered over the Metropolis. The company is authorised to carry out its operations by a special licence granted by the Postmaster-General, on the 28th of March, 1872. The licence describes the aim of the company as to carry out a system of exchange by telegraph, in which identical information is supplied from certain central stations or from certain determined points to any number of subscribers, by means of an automatic printing apparatus, which neither requires the use of local batteries, nor of clockwork, nor the presence of an attendant, nor necessitates any knowledge of telegraphy on the part of the subscribers.

A number of wires radiate from the central office, and each wire passes in zigzag form through a district in which there are subscribers, and is finally put to earth. The wires are tapped as they pass the clubs, hotels, or other institutions which have become connected with the company, and the printing instruments inserted so that all the printing instruments of any one district are joined in series. Each wire has its own battery at the central office, the number of cells

being varied according to the amount of work with which the wire is charged, that is to say, according to the number of instruments it contains. This number varies in the different districts from six or eight to fifty. Each battery is brought into action by means of a relay, and there are, therefore, as many relays working simultaneously as there are lines or batteries. The central office is also a general telegraph station, but the clerk who sits at the table, instead of writing out the message, reads it off from the tape of the Morse instrument as it unrolls itself before him, and, as he reads it, transmits the message to all the receiving instruments. During our visit to the central office at 17 and 18, Cornhill, a message from a correspondent began to appear on the Morse ink writer in less than one minute after it was handed in at a distant town, and at the same instant it was transmitted to all the receiving instruments of the company, and printed by them as fast as the Morse ink writer delivered it. A controlling instrument exactly similar to those of the subscribers stands in the central office, and supplies the home record of what is transmitted. On an average each instrument prints nearly 5,000 words a day, but on some days, when news is plentiful, as many as 15,000 words are transmitted.

We may mention at the outset that there are three kinds of messages supplied by the company, and each kind requires its own central office, its own form of receiving instrument, and an independent installation. Financial messages are printed from type-wheels, containing not only the letters of the alphabet, but also numbers, fractions, and signs. The second class of messages consists of short pieces of news that are printed in bold type on strips, that may be detached and pinned to the notice-board of a club or hotel. The type-wheels for these contain no fractions, and therefore work at a greater speed. The third class of messages consists of general news. The type-wheels in the instruments of this class need not contain figures, and are so light as to make a very high speed of transmission possible. Indeed, by an arrangement of the letters and a reduplication of *e* and *h* (the letters which occur most frequently), the speed of transmission now attainable with these instruments is greater than that with which the sending clerk can manipulate the sending apparatus. The currents supplied to the receivers first cause the type-wheels to revolve until the letter that is wanted is opposite to the tape, and then they stop it and bring the paper up to it so as to print the letter. Finally, they jerk the tape forward ready for the next letter. The wires leading to the instruments of the financial or first system are double, one wire conveying the current which turns the wheel, and the other the current which presses the tape against the letter. But in the case of the lighter instruments, Mr. F. Higgins has invented a method of effecting the double action with a single wire. For this purpose he introduces another small magnet which operates a contact-maker. This diverts the current from the type-propeller to the printing mechanism whenever a pause takes place in the rapid reciprocal currents which are transmitted to revolve the type-wheel. The effect is the same as that secured in the larger instruments with the double wire.

The subscribers of the first class receive at their own offices through the day the course of exchange and state of the markets within a minute of their being

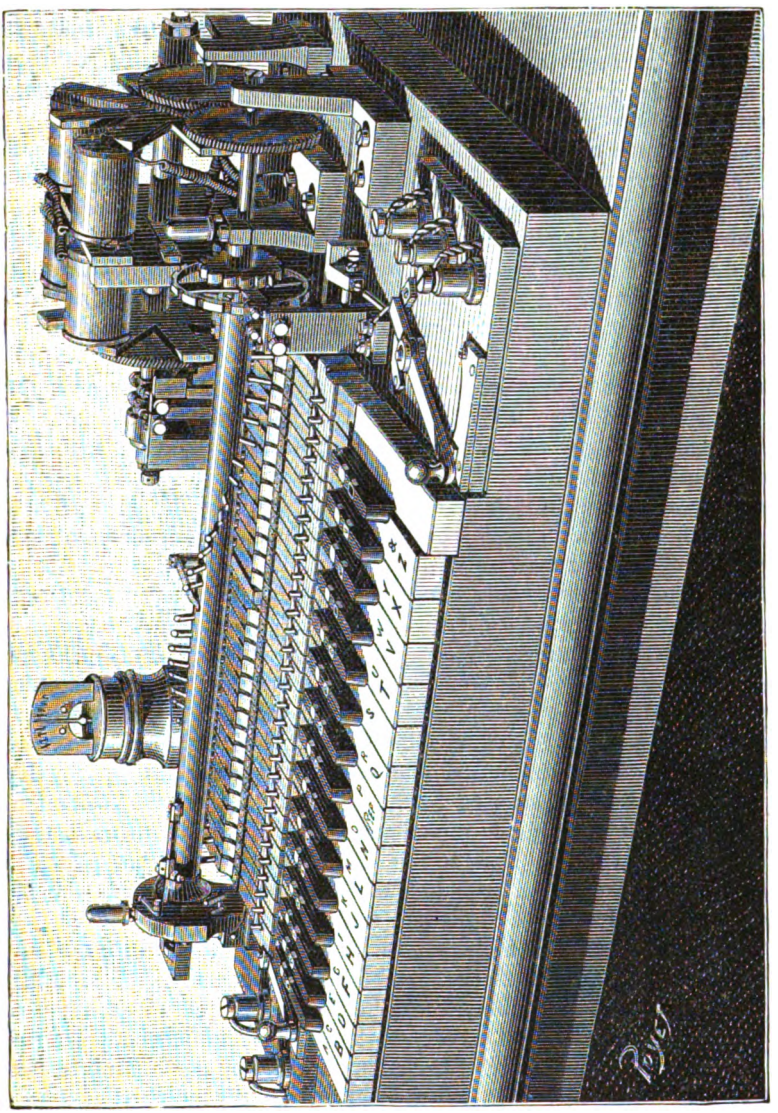


Fig. 775.—Transmitter of the Exchange Company's Apparatus.

officially stated at the Exchange; and no doubt this work, being the first undertaken by the company, gave to it its name.

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We are now in a position to examine in detail the instruments used in carrying out the system. These are the transmitter, or sending apparatus; the receiver, or printing apparatus; the relay, and the battery.

The *transmitter* is the apparatus by which the sending clerk produces the "making" and "breaking" of the circuit which are transmitted to the relays, and thence to the receivers in order to effect the impression. It consists of a revolving cylinder or commutator worked by an electric motor, and commanded by a pianoforte key-board, like the key-board of Hughes' apparatus (Fig. 772). This commutator is composed of a shaft or cylinder, on which is fixed a series of spurs or teeth arranged in the form of a helix, and turning in front of the inner extremities of the levers attached to the keys. When the clerk depresses one of these keys the corresponding spur is caught, and the revolving commutator is detached from the electric motor that works it. At the same moment a collar attached to the spur closes the printing circuit. When the key is released the printing circuit is at first broken, and an instant after the shaft again begins to revolve.

The motor is a simple magneto-electric motor supplied by a battery of potassic bichromate elements. The speed of the motor is regulated by the aid of a centrifugal governor which breaks the current when the speed reaches the rate which is intended to be the maximum. It is very sensitive to the smallest variations in the rate of rotation, and keeps the speed practically uniform. The governor can, however, be regulated to suit different systems and to allow of different maximum speeds.

This transmitter would easily work eighteen hundred receivers, and actually, at the present time, does work over five hundred.

The transmitter is furnished with a galvanoscope, which shows when a current passes, and two switches, one commanding the electric motor, and the other the relays. When the two switches are turned on the motor works, the cylinder turns, the relays close the circuits, and the type-wheels of all the receivers revolve synchronously with the cylinder of the transmitter. When, by depressing a key, the cylinder is stopped by the operator in a certain position, all the currents are simultaneously interrupted and all the type-wheels stop in the same position as the cylinder. It is at this instant that the current passes in the second wire and causes the attraction of an armature, which lifts the tape of paper against the wheel so as to produce the impression.

The Relays.—It would be difficult to transmit and to regulate the currents supplied to the various lines if they were emitted directly from the same battery, and therefore a separate battery, connected by means of a relay, is used for every line. This plan makes it easy to localise and remedy any interruption to the working that may occur. The contacts made by the transmitter act only on two distinct circuits, each of which consists of a number of relays, the electro-magnets of which are joined up in series. One group of relays commands the rotation of the type-wheels, and the other commands the printers or armatures that press the type-wheels against the tapes.

Fig. 776 represents one of these relays half-size. It consists of two short electro-magnets placed vertically, and having a horizontal armature which turns on a pivot at the end. The armature is held back by a spring, the tension of which is carefully regulated, so as to give it but little play. When the transmitter sends a current through the relays, the armature is drawn down and closes the battery contact of the corresponding line by bringing together two copper

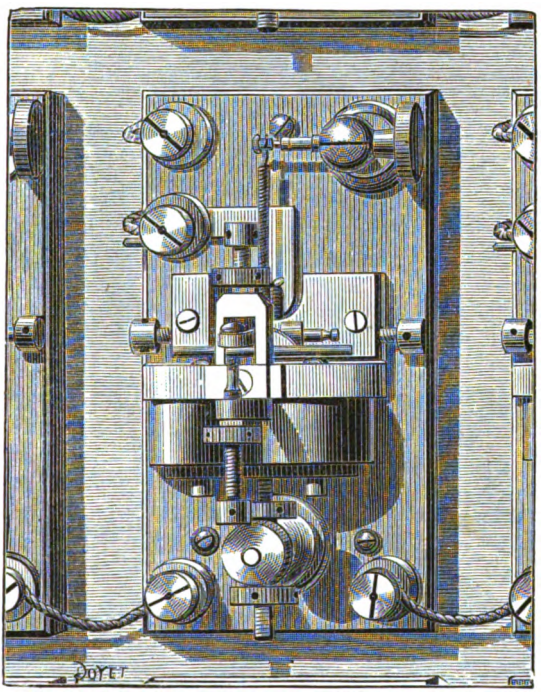


Fig. 776.—The Relay.

points, one of which is fixed, and the other carried by the armature itself. The cores of the magnet are short, split, soft iron tubes, which admit of being successively magnetised and demagnetised with great rapidity. The line is discharged by means of a condenser to prevent sparking.

The Receiver or Automatic Printing Instrument.—We have already pointed out that there are three forms of receivers in use, differing in size and speed of working. The instrument for printing general news is the smallest, and is, in fact, rather smaller than an ordinary Morse embosser. The receiver for the financial system is represented in Fig. 777. It has two type-wheels, each of which can take up two distinct positions by sliding lengthwise on an axle which also carries an escapement-wheel having teeth of a particular form. A clutch at

the end of a lever, attached to the armature of an electro-magnet, restrains or liberates the escapement-wheel as the armature oscillates under the action of the

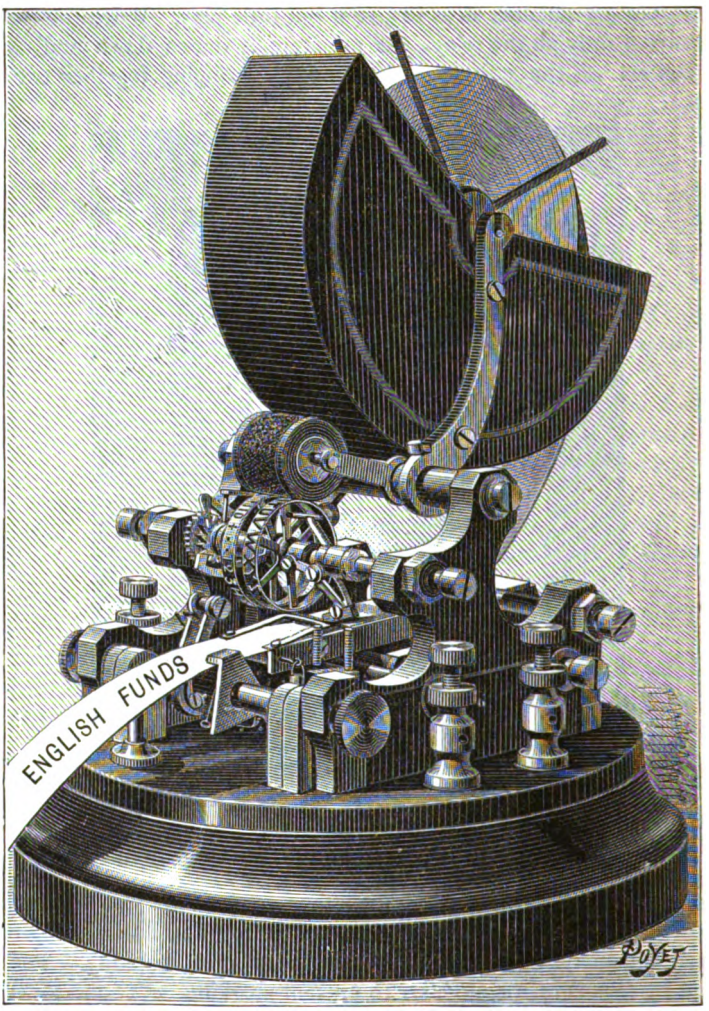


Fig. 777.—The Receiving Instrument.

electro-magnet. Each type-wheel carries on its edge twenty-eight characters and two blank spaces. One wheel has all the letters, and the other the figures and punctuation stops that have to be printed—there being sixty signs in all. The attraction of the armature under the influence of a single emission of current

makes the type-wheel turn through the space of one letter; the return of the armature under the action of a counteracting spring at the instant of the ceasing of the current also causes the wheels to advance another letter. Fifteen emissions of current, therefore, give to the type-wheel a complete revolution. The operator can produce any impression he likes with either of the wheels by first causing it to stop on one of the blanks, and then bringing into action the printing system commanded by the second circuit. In this position of the wheel the printing lever acts on a special mechanical arrangement which moves the type-wheels lengthwise in one direction or the other, so as to bring either the letter-wheel or the figure-wheel above the strip of paper. This motion of the wheels on the axis can only be produced when the wheels are stopped on one of the blanks. The printing apparatus commanded by the second circuit raises the paper against the wheel above it, so as to print the letter or figure, and then jerks it forward by means of a grip so as to space off the next letter. All the motions necessary to produce the impressions are thus produced by two electro-magnets worked by two distinct circuits without any mechanism resembling clockwork.

The instruments of the second and third class, having single type-wheels, are simpler in their action than that of the first class, which is represented in the figure.

It is now easy to understand the general working of the system. Let us, for the moment, confine our attention to the line traversing one district, and dispense with the relay, supposing the contacts to be produced and the currents forwarded by the transmitter directly. This simplification does not change the principle of action, for the object of the relays is only to multiply the contacts and the number of lines and instruments controlled by one operator.

The motion of the revolving commutator causes the circuits to be alternately made and broken, and short currents to be in consequence sent to the receivers. Here these currents give periodic impulses to the clutch which catches the toothed wheel attached to the type-wheel. The result is that the type-wheel of the receiver and commutator of the transmitter revolve synchronously. When the commutator stops, the type-wheel stops in the same position. If at this instant the second or printing circuit be closed by the operator, the current that flows lifts the printer and impresses the corresponding letter on the tape. When the operator releases the key, the commutator and the type-wheel revolve again until another key is depressed or the switch turned off.

We have not space to notice the many ingenious details that have been devised by the inventor and engineer of the company for securing absolute regularity and synchronism in all the instruments. By a very ingenious device of Mr. Higgins, the inventor, the wheel of every receiver sets itself at zero when the current is first started. If, therefore, by accident or intention a type-wheel be turned out of unison, so to speak, with the transmitter, immediately the current starts the wheel comes automatically back to zero. The receivers require but little attention beyond the occasional renewal of the tapes. The engineer

at the central office has everything so entirely under control, that he can detect and localise any defect in a very few minutes, and has at hand the means of promptly remedying it. On the whole, the work of this company is one of the most useful, as well as one of the most interesting products of the fruitful alliance of mechanical science with electricity.

CONNECTIONS AND AUXILIARY APPARATUS.

Relay Apparatus.—As a current which comes from a distance is often so weak that it is insufficient to work the electro-magnet that marks the paper, the relay is used, and a strong current is sent from a local battery through the receiving instrument. *The relay is a delicate form of electro-magnet, resembling the*

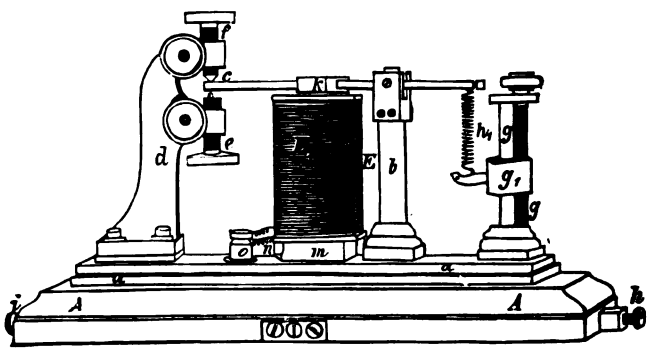


Fig. 778.—American Relay.

sounder, but having for object simply the closing of a contact, so as to bring a local battery into play. A great many different relays have been constructed, but they all may, however, be grouped in two classes, namely, polarised and non-polarised relays. The former are more frequently used in England than the latter, and are so called because their armatures are polarised either by means of permanent magnets near them, or by being themselves the poles of permanent magnets. One of the oldest non-polarised American relays is shown in Fig. 778. The brass plate *a a* is fastened upon the block A A, and carries the electro-magnets E E, the iron cores of which are connected with each other by means of the iron piece *m*. The bearings for the lever *c*, with its armature K, are attached to the pillar *b*. The motion of this lever is limited by the contact screws *e f*, fastened to the support *d*, which is insulated and fixed upon *a a*. The spiral spring h_1, the tension of which can be regulated by means of the guiding piece g_1 moving upon *g g*, keeps K from being attracted. The support *g g* is connected with the binding screw *k*; and screw *e*, which has a contact pin at the upper end towards the lever *c*, is connected with the second binding screw *i*. The screw *c* is mounted with ivory, and therefore does not influence

the current. The local circuit, which contains the local battery and the writing apparatus, is closed at *i* and *h*. When even a very weak line current passes through the coils of the electro-magnet E E_1, it will cause it to attract K, and contact will be made between *c* and *e*. The current from the local battery reaches the support *g* through *h*, flows through spring h_1, the lever *c*, and screw *e c*, from there through *d* and *i*, and so into the writing apparatus. As every line current which reaches the relay acts in the way described above, it is evident that the relay sends a powerful local current instead of the weak line current into the writing apparatus, and thus produces a distinct writing, no matter whether the sending station be at a short or long distance.

Siemens' Polarised Relay.—A polarised relay by Siemens is shown in Fig. 779. Down the side of the instrument and bent underneath it, passes the hard steel permanent magnet S N, the upper or s end of which is slit so that a soft iron lever can be pivoted in the slit at *a*. Upon the horizontal arm of the permanent magnet, which is bent at right angles, the electro-magnet E E is placed, and connected by means of the iron piece *m*. The cores, which pass through the plate A, have movable shoes *b b*, which are kept in the desired position by means of the screws *c c*. The armature is represented by the lever Z, pivoted at *a* between the south poles S S of the permanent magnet. The play of the lever is horizontal from side to side, and is limited by the contact screws *r t*, one of which ends in an agate point, and the other is insulated by means of the gutta-percha pieces K K, and can be adjusted by means of the screw *t*. The electro-magnet E E being placed upon the north pole N of the permanent magnet, the poles *b b* have north magnetism, whilst Z has south magnetism. The one or the other pole may be made to prevail by adjusting the lever. The action is therefore as follows: The pole N of the permanent magnet N S induces south polarity in the bar *m* and the ends of the cores next it, and therefore causes north polarity in the ends of the cores remote from it. Again, the pole S S induces north polarity in the end *a* of the lever *a z*, which is pivoted to it, and south polarity in the end which moves between the poles *b b*. The continuation of this lever beyond *z* is a non-magnetic metal, which is not affected by N S. When the lever *a z* is equally attracted by both poles at *b* and *b*, it remains equidistant from them, but when one pole is screwed a little nearer than the other it draws the lever to it. When the relay is at rest this is its position, the lever

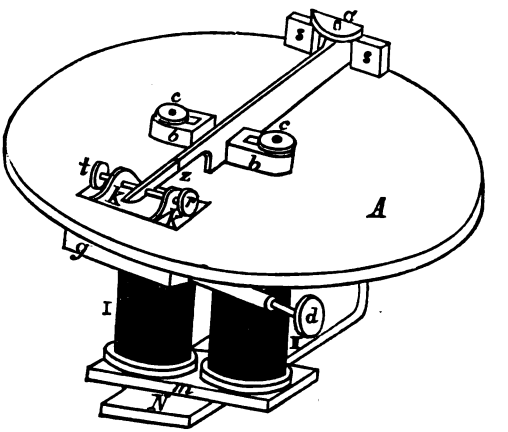


Fig. 779.—Polarised Relay.

then touching the agate point. When the line current enters the coils of the electro-magnets E E the poles are changed, that at the end *b* of II being strengthened as a north pole, and that at the end *b* of I being either weakened or reversed to a south pole. Hence the lever is drawn from the agate point to the opposite metal point *t*, and remains in contact as long as the line current flows, but falls away when this current ceases. The contact closes the local circuit which works the instrument. The polarised relay by Siemens has a resistance of 1,200 Siemens' units.

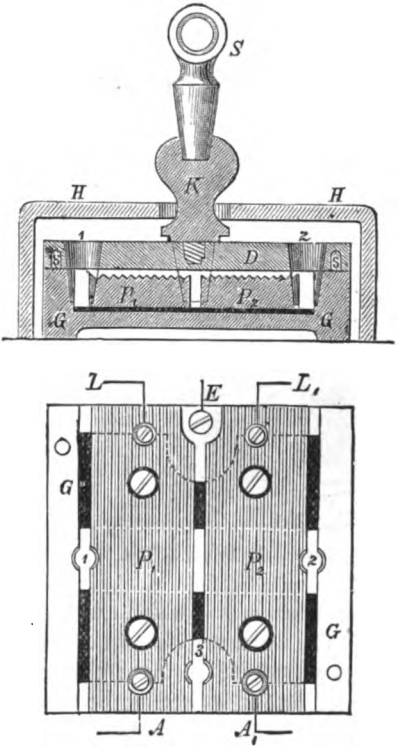


Fig. 780.—Lightning Plates.

Lightning Plates.—For the completion of a so-called Morse's system, besides the apparatus described, a galvanoscope and some arrangement for protection against lightning are required. The galvanoscope is used to indicate the presence or absence of a current in the circuit, the direction of the current, a test as to whether the apparatus is properly joined, and the presence of any faults in the line. Leads that are on the outside of buildings have to be protected against lightning, that is, every lead has to be connected with a lightning conductor. This is necessary both for the protection of persons employed, and also for that of the apparatus. Different forms have been given to these lightning conductors. Bréguet's, for instance, consists of brass plates, the toothed edges of which come very close to each other, so that the interval can be leaped over by currents of high potential, but not by an ordinary working current. The plates by Siemens and Halske, shown in Fig. 780, are very largely used at the present time. Two cast-iron plates P_1 P_2 are fastened upon the cast-iron ground frame G G, being grooved on their surfaces, and insulated by means of india-rubber plates. Opposite P_1 P_2 is placed the grooved cast-iron plate D; a distance of about 0·5 millimetre is left between the grooves of the former and the latter; *s s* are steel pins, which fit in the holes of plate D; D and G are connected with the earth-leads E; plate P_1 is connected with a line L and apparatus A, and plate P_2 is connected with line L_1 and A_1. The current coming, for instance, from the line L_1 will flow through the plate P_2 and then through A_1 to the apparatus, and from thence to earth, or through A, plate P, and the line L to the next station. Atmospheric electricity arriving from L_1,

however, will take the shorter way, that is, through plate P_2 and D, and then to earth.

Siemens' plate may also be used for changing the line connections. For this purpose the holes 1, 2, and 3 are bored in it, and fitted with the plug S; but under ordinary circumstances, S is inserted in the wooden knob K. When S is inserted in the bore 1, plate P_1 is connected with D, *i.e.* line L and A are connected with the earth; the same happens with L_1 and A_1 by inserting S into 2. By inserting S into 3, P_1 and P_2 are connected with each other, or (which comes to the same thing) with L and L_1, so that their own station apparatus is excluded. The apparatus just described is, as a rule, covered with a wooden case H H, which is screwed to the table. The case has only one opening, which is opposite the hole 3.

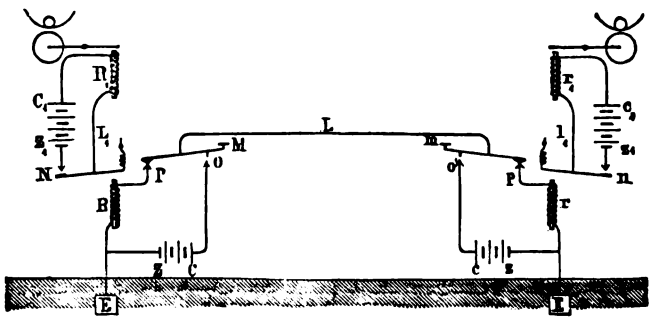


Fig. 781.—Morse Connections.

Connections.—In order that the mode of action of the Morse system, when completed with all necessary connections, may be understood, we shall now proceed to consider the connection of the several portions of the apparatus with each other, and also with the apparatus of another station, etc.

Fig. 781 shows the connection of a Morse system with relays, worked by single currents. The lightning apparatus and galvanoscope are here left out. M and *m* indicate the Morse keys, O *o* sending contacts, P *p* receiving contacts, R *r* the magnets of the relays, N *n* contact levers of the relays, R_1 r_1 the electro-magnets of the writing apparatus, C *z* and *c z* sending batteries, C_1 Z_1 and c_1 z_1 local batteries of both stations going. When no signalling is on, these stations are connected by means of the line L and earth-lead E E. When one station wishes to send a telegram to another, the following circuit can be closed by pressing down the key M upon O, so as to close the contact at O, and at the same time to open the contact at P: From one pole C of the sending battery, the current flows over O M through the line into the second station, thence it proceeds over *m p* into the electro-magnet *r* of the relay, and so to earth. The other battery-pole Z of the sending station is also connected with earth. The electro-magnet *r* attracts its armature, contact is made at *n*, and the local circuit of the receiving

station closed. The current now flows from one pole z_1 of the local battery over n_1, through the line l_1 into the electro-magnet r_1 of the writing apparatus, hence it proceeds to the second pole c_1 and so back to the local battery. The magnet of the writing apparatus attracts its armature, presses the pencil or printing wheel against the strip of paper, and reproduces the sign given by the key M.

Ink writers are, however, more frequently used without relays. In this case the ink writer is substituted for the relay and local battery, but otherwise the figure serves for both cases.

The connection of an end station by means of a relay is shown in Fig. 782. G represents a galvanoscope, and B a lightning plate. The current arriving from L flows over 2 into the plate *b b* of B through the battery B_1 and the galvanometer G, and then through the key T, which is connected with the electro-magnet of the relay; it then flows through the plate *a a* of the lightning conductor over 1 to earth. When the current is interrupted the spring R of the relay takes off the lever from the contact *c*, and makes contact at *d*, and thus the local circuit is closed as follows: The current flows from the local battery B_2 over 5 to *d*, through R into the writing apparatus A, and from here over 6 and back to the battery. For every interruption of current in the circuit a sign is produced in the writing apparatus of the end station. If the station is an intermediate one, and not an end station, the connection has to be slightly altered; this alteration is indicated by the thin lines in Fig. 782. The change is as follows: The plate *a* of the lightning plate is not connected by means of 1 to the earth-leads, but is joined to the line L_1.

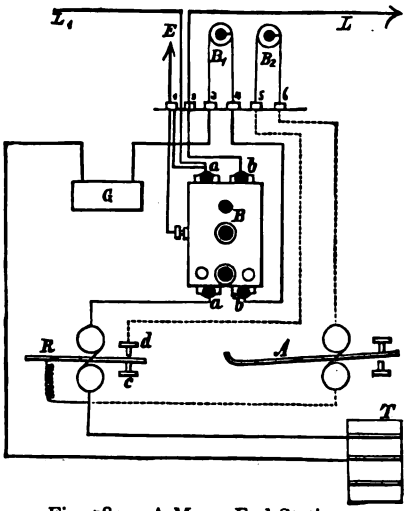


Fig. 782.—A Morse End Station.

Intermediate and Terminal Stations.—Arrangements are sometimes used to send on telegrams through an intermediate station to the end stations automatically, when the distance between the sending and receiving stations is considerable. The arrangements have to be different for the Morse, the Hughes, and the self-acting apparatus. For the Morse apparatus the connection is shown in Fig. 783. The lines L_1 L_2 are connected by the clamps 2 and 3 to the relay levers h_1 and h_2 at the intermediate station. The contact r_1 is connected with the electro-magnet R_2, and the contact r_2 with the electro-magnet R_1. The contacts t_1 and t_2 are usually connected with one and the same battery B. If, however, the resistances in the lines differ very much, a more powerful current is used for the larger resistance than

for the smaller. A telegram arriving, for instance, through L, is transmitted in the following manner: The currents from L_1 enter at 2, flow over h_1 to r_1, through the coils of the electro-magnet R_2 and then over E_1 to earth. In their passage these currents act on the relay and bring into play the battery B at the intermediate station, for R_2 attracts its armature, and causes the lever h_2 to make contact with t_2. Now as one pole of battery B is connected to earth by

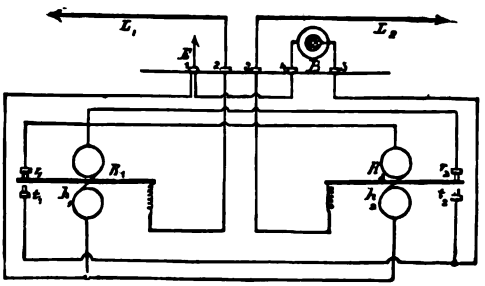


Fig. 783.—Connection of Intermediate Station.

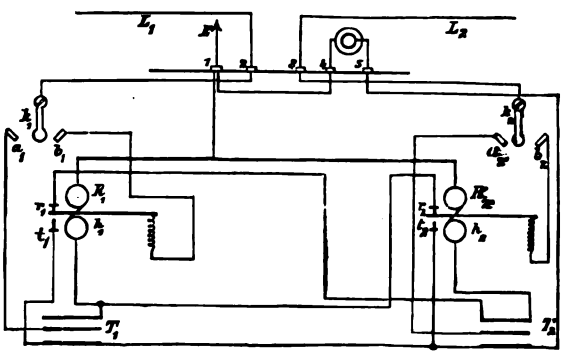


Fig. 784.—A General Station.

means of 4, when the contact t_2 is closed by the relay the current flows from the second pole over 5, t_2, the lever h_2, and thence over 3, to the line L_2. A similar action takes place when the sending occurs in the other direction. A current coming from L_2 flows over 3 h_2, r_2, R_1, E_1, to earth, whereby h_1 is caused to make contact with t, and a current is sent from battery B over 5 t_1 h_1 and 2, into line L_1.

Fig. 784 shows the connection of apparatus for a station which is to be used either as an intermediate or as an end station. k_1 and k_2 indicate the commutators with their contacts a_1 b_1 and a_2 b_2; T_1 and T_2 are Morse keys. By pushing the two handles to the right so that k_1 makes contact with b_1, and k_2 with b_2, the station is connected as an intermediate station. If, for instance, a current

arrives from L_1 it will flow over 2 k_1 b_1 h_1 r_1, to the contacts of key T_2, then through the electro-magnet R_2, over I to earth at E. The relay is by this means brought into play, and the lever h_2 makes contact at t_2, sending the current of battery B over 5 t_2 h_2 b_2 k_2 and 3 to line L_2. When the handles are pushed to the left a current arriving from L_2 flows over 3 k_2, a_2, T_2, into the coils of the electro-magnet R_2, and from here over I to earth E. Although the lever h_2 makes contact with t_2 the battery is not connected with line L_1 or L_2, as may be seen from the figure, and therefore the station acts as a terminal receiving station. We need hardly mention that polarised relays may be advantageously used for transmission in all these cases.

It would not be advisable to employ the Hughes apparatus at the intermediate station in the same manner as the Morse apparatus is connected, first, because the Hughes apparatus is too expensive; and, secondly, because it would be necessary to employ four Hughes instruments, which would have to be made to move synchronously. Many proposals have been made for transmission on to a Hughes apparatus, but we need only describe one of them, namely, the arrangement shown in Fig. 785.

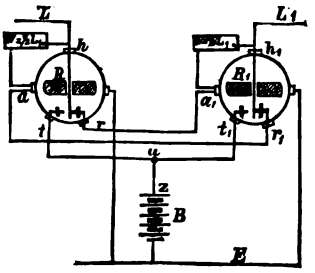


Fig. 785.—Connection for the Hughes Apparatus.

R and R_1 represent Siemens' polarised relays, r r_1 and t t_1 being their contacts. The lines L L_1 are joined to the relay levers at h and h_1, and are connected with the electro-magnet through a and a_1. W and W_1 are inserted resistances; a is further connected with the contact r_1, and a_1 with the contact r. The contacts t and t_1 are connected with the zinc pole of battery B. The second ends of the wires of the electro-magnet are joined to the earth-leads E. As the resistance W is equal to half the resistance of line L, and resistance W_1 to half the resistance of L_1, the resistance which the circuit offers to the electro-magnet of the relay R is equal to $\frac{2}{3}$ of the resistance of L, and the resistance which it offers to the electro-magnet of R_1 is equal to $\frac{2}{3}$ of the resistance of L_1. When a current passes through the line L_1 to the intermediate station, it flows in the following directions: The line current divides at h_1 into two portions, the larger of which flows through the rod which offers it the least resistance, that is over r_1 or through the coils of the electro-magnet R, and then to earth E; the weaker portion flows from h_1 through the resistance W_1, until it reaches a_1; here it divides again—one branch flows from a_1 through the coils of R_1, and then to earth; the other flows from a_1 over r and h to the line L. The strongest of these three branch currents, that is the one over r_1, reaches the coils of the electro-magnet R, and causes the lever of R to make contact with t, thus making the passage of the current of battery B as follows: From u, over t, through the lever of the relay to h, and then to the line L; no resistance being inserted here, the greater portion of the battery current will flow to the Hughes

apparatus at the end station. As h is connected with a, a branch current will also take this course, but in consequence of the inserted resistance at W, will only be a very weak one. This branch current again divides at a, one part flowing through the coils of R to earth, whilst the other part flows over r_1 and h_1 as counter current into the line L, and from there to the Hughes apparatus. The electro-magnet R is, therefore, influenced by two currents, one coming through L_1 h_1 r_1, namely, the line current; the other coming from B over u t h W and a, namely, the battery current. The latter circulates through the coils of the electro-magnet at the very moment when the former causes the lever of R to make contact. The first current having the direction opposite to that of the latter, it follows that the battery current will cause the lever of the relay R to be brought back again upon the contact r. When the Hughes apparatus is used, it is necessary to employ the opposition current, which will force back the armature at the required moment into its first position, that is to say, the position of rest.

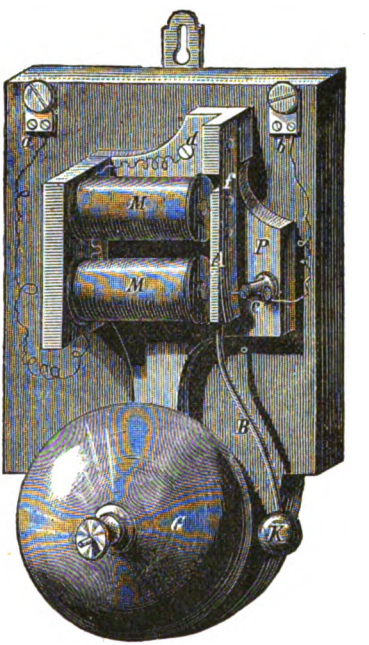


Fig. 786.—Electric Bell.

Calls and Alarms.—To signal from one station to another, bells, as a rule, are used. These bells are generally similar to those already described when we were considering the telephone installations. Fig. 786 represents a simple and common form of bell, the hammer of which is attached to the armature of an electro-magnet. The current enters the screw a, flows through the coils of the electro-magnet M M, and passes to the screw d and spring f, which carries the armature A; from f the current flows through the contact pin c to the second pole-clamp b. The armature is attracted by the magnet, and the arm B with its hammer K strikes against the bell G; whenever this happens the contact is broken between c and f, and the armature returns to its original position and makes contact again.

Telegraph Leads.—Many of the arrangements and precautions which we have described in connection with telephone installations are applicable to telegraph lines, except that it is not so necessary to provide against the induction of parallel wires. Telegraph lines are open and overlaid (*i.e.* overhead wires), or covered and underlaid (subterranean and submarine).

An open line of telegraph requires supports, wires, and insulators. Supports may be of wood or iron. In England, however, wood is employed chiefly, because it is three times as cheap as iron, and is a better insulator when dry.

The wood generally used is either native-grown larch or Scotch fir. To prevent decay the wood is usually seasoned and dressed or pickled. The seasoning is for the purpose of getting rid of the sap, and is effected best by exposure to free currents of air. The means used for the preservation of timber may be applied externally or internally.

Charring and tarring are external applications. The charring consists in roasting the butt-end of the pole over a slow fire. The tarring coats the thick end with a mixture of three parts of Stockholm tar, seven parts of gas-tar well boiled, and three parts of slaked lime. Wood is *kyanised* by impregnating it with certain metallic salts, such as corrosive sublimate (perchloride of mercury). Chloride of zinc, and copper sulphate, have also been used in a similar way, and the three methods have been named after their respective discoverers Kyan, Burnet, and Boucher.

Another useful application is creosote, an oily coal-tar product formed in the distillation of coal. It is prophylactic and antiseptic, preventing disease and destroying the germs of animal life, besides which, when forced into the pores of the dried wood, it makes it impervious to moisture. Of all the processes for the preservation of timber, creosoting has given the most universal satisfaction.

The Wires.—Iron is the material employed in open telegraph lines. Copper, though a better conductor than iron, is not so good for suspended lines, as it stretches, soon loses its elasticity, and is much affected by temperature. The wire in general use for all through-circuits is No. 8 (diameter ·170 inch). No. 11 (diameter ·125 inch), is used for short circuits of minor importance. Iron wire ought to be covered with a coating of zinc (galvanising).

Insulators.—Of the substances in the list of non-conductors on page 36, some may be excluded for the purpose before us on account of want of durability.

Glass possesses high resistance to the passage of electricity, and has a smooth hard surface; but it condenses the moisture from the air on the surface so as to destroy the insulation, and is very brittle. Ebonite offers a very high resistance and is strong, but its surface deteriorates rapidly, becoming cracked and fissured, so as to retain both dirt and moisture. Earthenware is the material from which most of the insulators are made, the better kinds being of glazed porcelain, the commoner of glazed brown pottery ware. The form given to these is usually that of an inverted cup or bell. The most perfect form of insulator will be that in which the surface exposed is a minimum, and the wire is as far as it can be from the main support. That which is in most general use in England is the insulator of Mr. C. F. Varley. It is made in porcelain and also in brown earthenware, and is shown in Fig. 787. It consists of two distinct and separate inverted cups (*a* and *b*), fitted into each other by cement. The inner cup screws into the outer, and is cemented to an iron stem C, which serves as a bolt to fix it to the cross-bar or arm D. The wire is placed in the groove of the insulator and very

tightly bound to it. The two cups have recently been made in one by being united at the upper end. Another insulator, lately introduced by Messrs. Johnson and Phillips, is an inverted porcelain bell curved inwards at the bottom so as to form a ledge or furrow all round it. This channel is filled with an insulating oil.

The supports for the insulators are either wooden arms or iron brackets. The arms in England are formed of oak.

No. 16 galvanised iron wire is employed for binding purposes. The form of joint now adopted is that introduced by Mr. Edwin Clark, and known as the Britannia joint. The ends of the wires are carefully scraped clean for about two

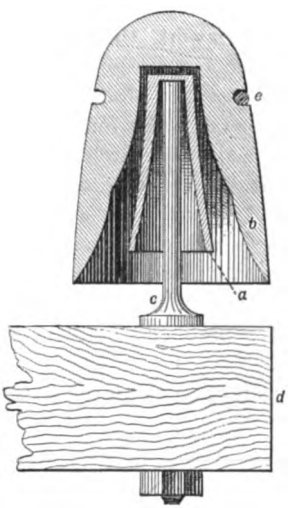


Fig. 787.—Varley's Insulator.

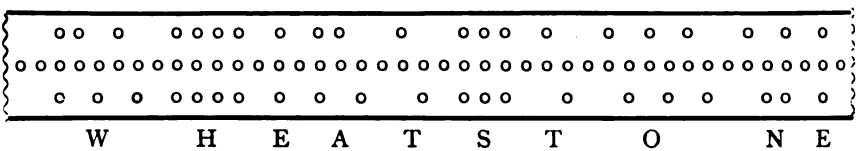
inches, and laid one over the other, they are then bound firmly together with wire, are smeared with chloride of zinc, and solder is applied in the usual way.

AUTOMATIC TELEGRAPHY.

The object of automatic telegraphy is to give the telegraphic signs more quickly and more correctly than they can be given by the hand. The hand of the operator has a limited speed of working, and both that and the attention or mental strain soon tire. Hence the messages sent by hand soon lose their clearness. Moreover, interruptions and varying conditions of health tend also to render hand-signals illegible. Mechanical means therefore have been devised for assisting the sending clerk, and securing precision. Bain first proposed a plan in 1846 to work with his chemical marking. He punched holes and slits in a ribbon of paper to mark the dots and dashes of the messages, and by drawing the ribbon at a uniform speed beneath conducting brushes over a metal roller, caused contact to be made at corresponding intervals.

The Wheatstone System.—Wheatstone's system of punching has replaced Bain's so far as England is concerned. The punching is done by a special instrument called a *perforator*. It has three keys, one of which is connected with a single punch; a second moves a single punch in a line with the first, together with two other punches, one above and the other below; the third key works two punches in a line with the first, together with a punch above the first, and another punch below the second. Whenever a key is depressed the paper is jerked a step forward. The marks made by the three keys are therefore as follows:—first o, second $\overset{o}{o}$, third $\overset{o}{o}\ \overset{o}{o}$. The first is understood to mark a space, the second a dot, the third a dash. When the punched paper is drawn by clockwork through the transmitter by means of a spur wheel that catches in the central line of holes, the side holes let pins on an oscillating lever make contact alternately with the positive and the negative pole of the battery. The holes for a dot allow a reversal of current at each oscillation; those for a dash, at each second oscillation. The *receiver* is an ink writer of a sensitive kind, so constructed that to make the disc mark a current has to be sent in one direction and has to be followed by a current in the opposite direction. A dot is written by sending a transient current in one direction to move the disc, another immediately after to bring it back. A dash is written when the reverse current follows the first at a longer interval. But these currents are just what are produced by the contacts through the punched paper in the transmitter.

The following is a word, as it appears on the punched ribbon:



This automatic apparatus is used in England for ordinary messages on long lines that are much worked, and for the transmission of news on lines to provincial centres. Several clerks can be punching the messages as they arrive, while another is transmitting. The rate at which the latter clerk can despatch the message is more than double that at which he could send with a Morse key. The average rate of working on long circuits with Wheatstone-punched ribbon is about seventy-two words per minute. For short circuits, however, and circuits that are not often charged with a glut of work, it would be a needless expense to fit up this apparatus, for nothing would be gained by delaying the transmission of the message until it is punched, the line and sender being idle meanwhile. The method lends itself admirably to the transmission of news; for one punched ribbon can be used again and again in wiring to different centres the same message.

Alteneck's System.—Fig. 788 represents the system of Hefner Alteneck, which may be conveniently described in this place, as, although it is worked by keys, it combines some of the time-saving qualities of an automatic apparatus. The combination of dots and dashes which form any letter or sign are produced by the depression of a single key. Each key operates by means of levers and wheelwork on a pointer connected with the case D shown in the figure. There are forty-nine keys, here arranged in seven rows; the arrangement being such that the letters, signs, etc., which occur most often are nearest the hand. An enlarged representation of a single element of the case D may be seen in Fig. 789. Each key T is connected by means of a lever with a vertical sheet of

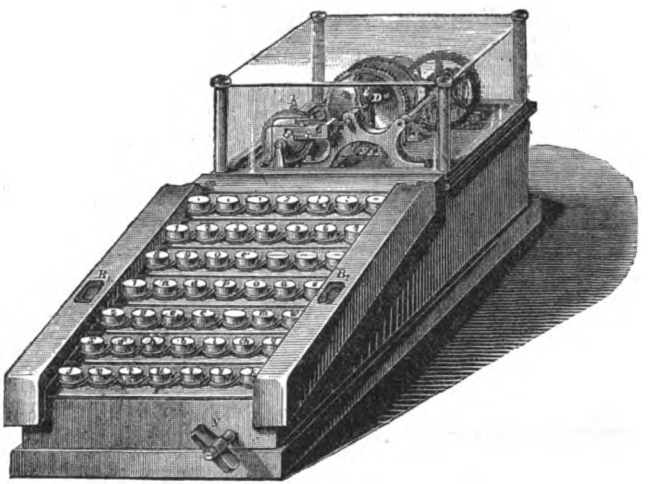


Fig. 788.—Alteneck's Automatic Telegraph.

metal S, which has the letter or sign of the key filed out on its free edge; opposite to these sheets of metal S, nineteen horizontal metal strips Q Q are placed, and behind these a corresponding number of levers H, which are also of sheet metal. The reason for this number will be apparent on examining the length of the longest letter. A dash in the plate S will thrust in three strips, but a dot only one. The longest sign is the nought, which consists of five dashes, separated by four spaces, and therefore requires $3 \times 5 + 4$, or nineteen strips. The levers operate in the following manner to liberate the case D, and to allow it to turn under the influence of its driving weight: The rods *n*, which stand opposite the edge of case D, are fastened to the upper arms of the levers H, and are placed so as to work upon a number of little rods *s s*, which may be pushed a little beyond the surface of the case. The edge *a c* of the case has also teeth which are cut crossways, and in which the trigger *f* catches. When a key, T, is depressed, the strips of metal Q Q, corresponding to the projections on the free edge of the vertical metal plate S, are pushed forward, and affect the corresponding levers H,

which in turn transmit the movement to the pins *s*. The driving weight operating by means of the system of wheelwork, tends to turn the case, but the motion is prevented so long as the catch *f* lies between two teeth. When, however, a pin *s* is pushed forward by means of *n*, the catch is removed and the wheel is allowed to turn. In this manner the contour of s is reproduced on the edge of the circumference of D. The letters are transmitted from D by means of the pointer *i*, and the bent lever *o*, which is connected with the lever C. Before the action begins, the contact lever C is forced against the stationary contact by means of a spring, but when the lever O is turned, the pin V is pushed out, and C is forced against the working contact. At the same time the pointer *i*, by passing its end over the projecting pins *s*, brings about the corresponding duration of current, as well as the appearance of the current at the right time. The proper duration of the current can only be obtained when, besides the pushing forward of the pins *s s*, the pointer is also made to move with relative velocity over each group of pins. To bring about this result the case, which rotates in a jerky fashion, is connected with the pointer in the following manner: The shaft of the case is hollow, and through it passes the shaft of the pointer. The case, with its fly-wheel M, bears but lightly on the shaft *m* of the pointer, and at this point one end of a spiral spring, F, is fastened to *m*, while the other end is joined to the frame. When the case rotates, the pointer moves with it, but at the same time the spring is strained, and tends to bring the pointer back to its starting point A. Hence the projecting ends of the rods *s* move across the end of the pointer, and contact lasts for the interval of a dot or dash as the case may be. To make the motion uniform, the toothed wheel K, which is fastened to *m*, drives a small wheelwork which sets the fan W in motion so as to act as a regulator. When the telegram has been transmitted, the pins *s s*, which had been pushed forward, are again brought into their former position by means of an inclined plane not shown in the figure.

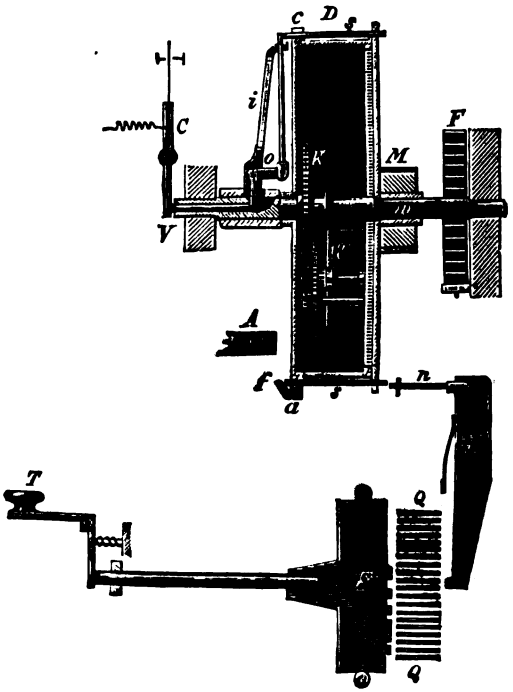


Fig. 789.—Alteneck's Automatic Telegraph.

DUPLEX AND MULTIPLEX TELEGRAPHY.

By duplex telegraphy is meant the sending of two telegrams in opposite directions at the same time through the same wire. The various methods are all based on the principle of registering alterations in the strength of the current flowing through the line. Such alterations have been obtained by two methods, namely, (1) by using differential relays, or, which is the same thing, by a separation of the two coils of a relay, or (2) by means of a Wheatstone bridge.

The Differential Method.—The system in which the coils of the relay are separated from each other, is shown in Fig. 790. The Morse keys *a a* have auxiliary levers *b b*, connected with the relay coils R_1 and R_2, which are independent of each other. The batteries B B are connected with the Morse key;

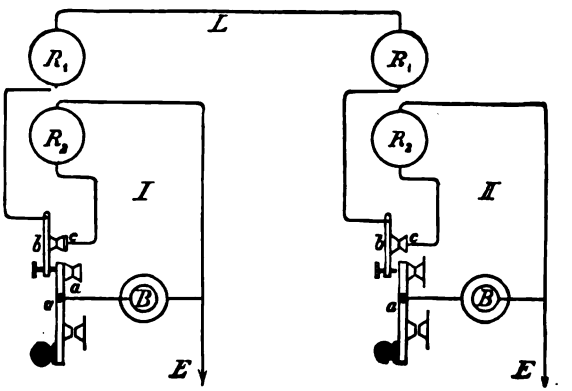


Fig. 790.—Differential Method.

L represents the line which connects the two stations I and II with each other. The batteries of both stations, as may be seen from the figure, are put in series. Let us assume that the key *a* is depressed at station I only, then contact between *b* and *c* is broken, and the current flows from the battery B over *a* and *b* into the coils R_1, thence from the one arm of the relay, and so through the line to station II. As the spring of the relay lever is very powerful, the current which circulates through one arm only of the electro-magnet is not sufficiently powerful to attract the armature. When the current arrives at station II, and reaches the coils of R_1, it flows over the contact *b c* of the auxiliary lever, and from here through the coils of the second electro-magnet arm R_2, and so to earth E. When the current circulates through both arms of the electro-magnet of station II, the magnet becomes sufficiently powerful to overcome the force of the spring.

When both keys are depressed at the same time the current flows as follows: From the battery B of station I, over *a b* and R_1, through the line L to station II, through the coils of the electro-magnet R_1, and then over *b* and *a*, to battery B of

II, and then to earth. The relay of station II will not be affected by the current, because only one arm of the electro-magnet has a current passing through it, unless the batteries B B of both stations have been put in series. By the simultaneous depression of the keys of both stations, the coils of the electro-magnet R_1 are connected with the battery of station II, so that the coils have the currents of both batteries flowing through them, and the increased force of attraction of the one magnet R_1 of station II is sufficient to overcome the force of the spring. The same holds good for station I. The result is that the depression of *one* key acts on the distant station, but the simultaneous depression of *both* keys acts on both stations. The arrangement therefore permits of telegrams being sent at the same time in opposite directions through the same wire.

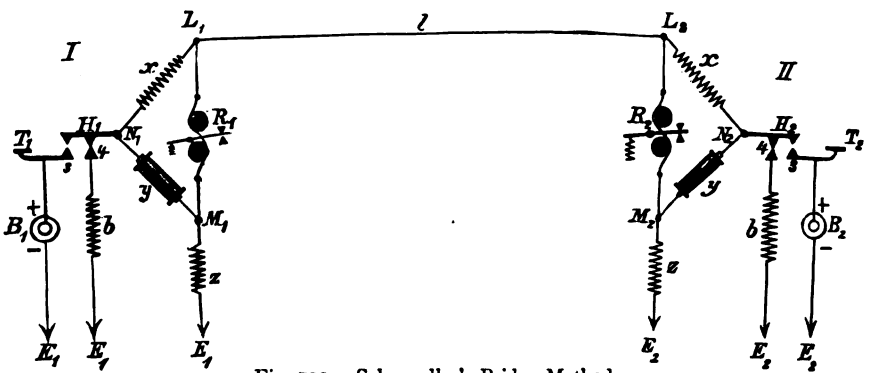


Fig. 791.—Schwendler's Bridge Method.

The Bridge Method.—The method devised by Schwendler, in which he uses a Wheatstone bridge, is shown in Fig. 791. At the distant stations I and II, B_1 and B_2 indicate equally strong batteries, the zinc poles of which are connected at both stations with earth, whilst the copper poles are connected with the keys T_1 T_2. Above these keys are what may be called the auxiliary levers H_1 and H_2. The contacts 4 of the auxiliary levers are connected by means of the resistances *b* with the earth. From the auxiliary levers lead the branches $N_1 L_1$, $N_2 L_2$, $N_1 M_1$, $N_2 M_2$. The ends of L_1 and L_2 are connected with each other by means of the line *l*. The ends M_1 and M_2 are connected with earth through the resistances z, and $L_1 M_1$, $L_2 M_2$ are connected with each other. The resistances *x* and *y* are inserted in the branches, and a *receiving apparatus* is inserted in the connecting line of every two branches. These are represented by the relays R_1 and R_2. Let us consider two cases—first, when only one station is active, and secondly, when both stations are active. When the key T_1 at station I is depressed, the contact between H_1 and 4 is broken, and contact is made between H_1 and 3. From the battery B_1 a current then flows over 3 and H_1 to N_1, and from here partly through the resistance *y*

over M_1 and the resistance z to earth, and partly through the resistance x over L_1 into the line l. The distance $L_1 M_1$, which contains the relay of the sending station I, remains without current. When the current arrives in station II at L_2 it divides into two branches, one of which flows over $L_2 M_2$ through resistance z to earth; the other flows through the resistance x over H_2 to 4, and then through the resistance b to earth. At the receiving station II, therefore, the branch $N_2 M_2$ forms the bridge, which is without current, and the relay R_2 lies in the branch $L_2 M_2$, through which a current flows. If, however, both stations work at the same

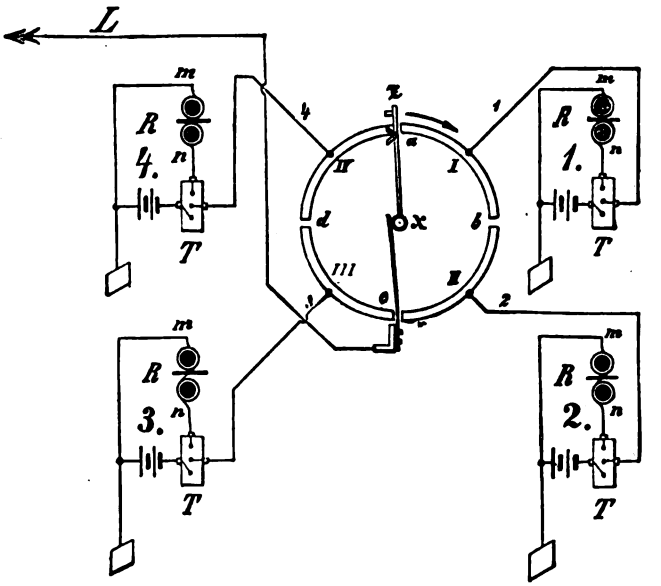


Fig. 792.—A Quadruplex Telegraph.

time, the contact between H_2 and 4 will also be broken in station II, and that between 3 and H_2 made. From battery B_2 therefore a current will also flow over T_2, 3, H_2, x, L_2, and then into the line l. This current being opposite in direction to that sent from station I into line l, and both currents being equally strong, their effects in the line l will be neutralised, *i.e.* line l will be without current. In each station, therefore, a local current is formed, whose course for station II, for instance, is as follows: The current flows from B_2 over T_2 3 and H_2 to N_2, where it divides in the branches $N_2 M_2$ and $N_2 L_2 M_2$, both branches unite again at M_2 and flow over z to earth E_2. The relay R_2, lying in a branch through which no current flows, will, therefore, be affected. The method just now described can only be employed successfully when the resistances in the several branches are calculated according to the law of proportion for Wheatstone's bridge.

Multiplex Telegraphy.—The principle of Multiplex Telegraphy is a very simple one, and can be made clear with the help of Fig. 792. It represents

a station with four Morse systems; R are the writing apparatus, T the keys; each system is connected with one of the sectors I—IV. The line L is connected by means of a sliding spring with the axis x, which is made to move by clockwork, and which causes the pointer $x\,z$ to slide over the insulated contact pieces I, II, III, and IV in the direction indicated by the arrow. By this arrangement the writing instruments 1 to 4 are connected with the line in turns, and each remains in this position for a quarter of a revolution of the pointer. A second station B, which is connected with A by the line, is fitted in exactly the same manner, and the pointers $x\,z$ at both stations move isochronously, *i.e.* the pointer of station A moves over sector I when the pointer of station B moves over sector I, and so on. Apparatus 1 of station A will, therefore, be connected with apparatus 1 of station B by means of the line, as long as the pointers $x\,z$ move over the contact piece I. The apparatus 1 can therefore send and receive signs. When the pointers of both stations have reached sector II the apparatus 2 of the two stations will be connected, and this will continue until all the apparatus have been connected, that is, until the pointers have made one complete revolution.

This explanation is probably sufficient to make the principle understood, but to show the details of the connections we must examine a complete system in which the above principle is applied; for this purpose we will select the Multiplex apparatus by Bernhard Meyer.

Meyer's Multiplex Telegraph.—Each of the four attendants has to use his quadrant, so as to give all the necessary signs during the time allotted; but to send the call-signal involves a task which would be beyond the powers of any one key without a special contrivance. In order to make this possible several keys are connected with each other, so that by depressing one key, two or three more are depressed at the same time in a manner to be described later on.

Each quadrant, Fig. 793, is subdivided into twelve parts (1 to 12); the parts 1 to 11 are connected with the axes of the eight keys I^1 to IV^1 and I^2 to IV^2. The rest of the contacts of the keys I^2 to IV^2 are connected with the portions 3, 6, 9, and 12, and the remaining contacts of keys I′ to IV′ are connected by means of the branches e_2 e_5 e_8 and e_{11} with the portions having the same numbers. When the key I′ is depressed, and the pointer $x\,z$ makes contact with the portion 1, a current will flow from the battery B over i, the key I′ at $b\,o$ to II, and through the pointer $x\,z$ into the line. When all the upper four keys I′ to IV′ are depressed at the same time, a current will first flow through the portion 1 into the line at the moment when the pointer $x\,z$ glides over 1. A second current follows as soon as the pointer has reached the portion 4; a third and a fourth current reaches the line when the pointer has reached the portions 7 and 10. By depressing four keys at one and the same time, four different current impulses can be produced, which, therefore, may be used for producing four separate Morse signs at the receiving station. The nature of these signs (points or dashes) depends upon the duration of the several currents, and their duration depends upon the velocity with which the pointer moves and the length of the contact

pieces 1, 4, 7, and 10. If the pointer moves with uniform velocity and the different contact pieces are of equal length, the four currents will be of equal duration, and four equal signs will be produced. The four signs obtained by depressing the keys 1′ to IV′ are points. These keys are, therefore, called point-keys, and the contact pieces 1, 4, 7 and 10 are called point contact pieces.

It will only be possible to send a current like the one described when the pointer has passed the second, third, and fourth quadrant, and has again reached the first contact piece of quadrant 1.

Suppose we depress the lower row of keys 1^2 to IV^2, currents will flow from the battery through the different keys, and through the contact pieces

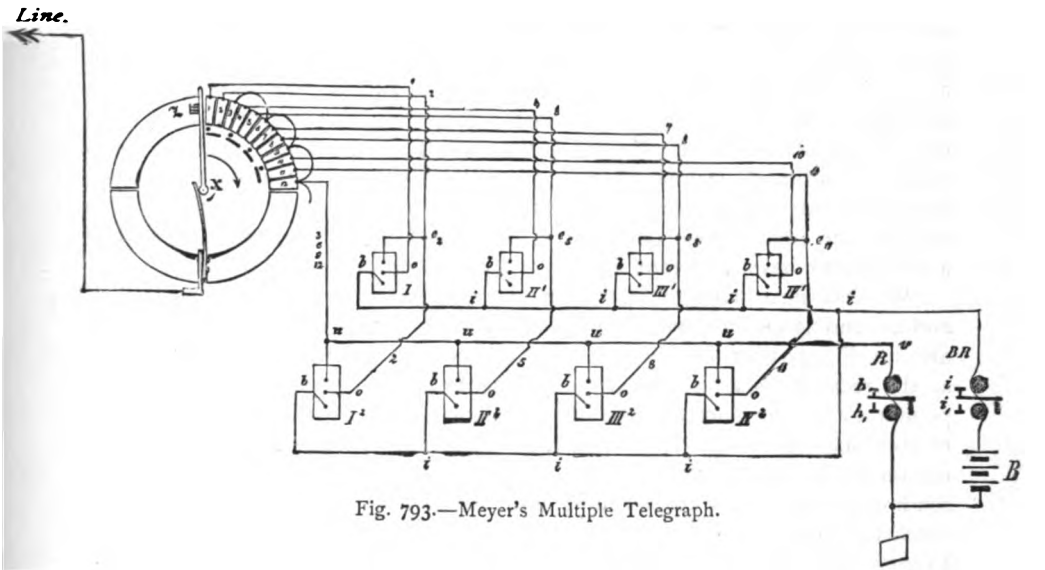
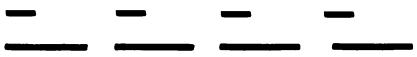


Fig. 793.—Meyer's Multiple Telegraph.

2, 5, 8, and 11, when the pointer touches the latter. The direction of current for key 1^2, for instance, is as follows: From B over *i i* . . through key 1^2, from *b* over *o* through 2 2 to the contact piece 2, then through the pointer *x z* into the line. The circuit of key 1^2, however, branches off at e^2, and allows the battery current to flow with the line as long as the pointer *x z* does not make contact with piece 2 by the depression of 1^2, but remains upon contact piece 1. The current now flows from e^2 over *b* of key 1′ and o into contact piece 1. The same phenomena occur when keys II^2, III^2, and IV^2 are depressed. If the receiving apparatus is, as before, an ordinary Morse writer, four signs are produced. These signs will be dashes, because the current is not only maintained during the time the pointer glides over one contact, but also when two contacts are passed, on account of the branch at *e*. The first current lasts till contact pieces 1 and 2 are passed, the second current till 4 and 5 are passed, the third till 7 and 8 are passed, and the fourth till 10 and 11 are passed. The signs

produced by depressing the upper keys and lower keys will be of the following nature:



The contact pieces 2, 5, 8, and 11 are called "complementary" contact pieces, and the keys belonging to these are called "dark keys." Those Morse signs are marked on the first quadrant of Fig. 793, as they can be produced by means of the twelve contact pieces.

In Meyer's system not only is the length of the signs of importance, but also their position: this greatly simplifies matters, because each written character needs at the most only four Morse signs. In the ordinary Morse writing, a point, for instance, signifies the letter *e*. In Meyer's Morse system, however, a point signifies in the first place the letter *e*, and in the second place a full stop, or thirdly a (punctuation) dash. Meyer's system not only saves room on the contact disc, but also saves time on the line. Each quadrant corresponds to a branch station, at each of which one attendant must be placed; four attendants will therefore produce four characters in one unit of time. The unit of time (that is, one complete revolution of the pointer) is taken as half a second; we have, therefore, $60 \times 2 \times 4 = 480$ characters per minute.

We shall next trace the direction of the currents to the receiving station, and as sending and receiving stations make use of the same apparatus, we may also use Fig. 793 for this purpose. Let us first assume that the current arrives at the receiving station just at the moment when the contact brush *z* of the pointer *x z* is in contact with the first quadrant of contact piece 1; the printers of both stations move synchronously, and therefore it follows that this current can only have been sent through the contact piece 1 of the first quadrant at the sending station. This current flows into the receiving station over *x z* and the contact piece 1 to key 1^1, then to e_2, over 2 to key 1^2, and then to *u v*, flowing to earth through the relay R, which it will therefore bring into action. Again, let us assume that the current is sent at the moment when the points of both stations make contact with the contact piece 2. The current arrives through the line, flows over *x z* to the contact piece 2, through 2, e_2, 0 to key 1^2, through *u v* and the relay R, to earth. A current reaching the station through the contact piece 3 would flow over 3, 6, 9, and 12, over *u v*, through the relay R, and then to earth. The currents for the point contact pieces 4, 7, and 10 would exactly correspond to those of the contact piece 1, of contact piece 2, of complementary contact pieces 5, 8, and 11; and to those of contact piece 3, and the separating pieces 6, 9, and 12. Each current then arrives at the station and flows to earth through the relay.

The same holds good for the twelve contact pieces of the second, third, and fourth quadrant. The receiving relay will, therefore, be affected by each current, irrespective of which contact piece or quadrant the pointer happens to be on. For every revolution of the pointer, four characters would be produced in the

following order: First character of the telegram sent from 1, first character of the telegram sent from 2, and so on. Then second character of telegram from 1, second character of telegram from 2, etc. etc. After mixing the four telegrams in this manner it would be difficult to re-arrange them again. It is, therefore, necessary that the separate telegrams should be received separately at the station which is affected. This is done by using four writing instruments at the receiving stations. The connection of these, and also the natural arrangement of the eight keys of one quadrant, are shown in Fig. 794. The disc is further furnished with two concentric contact rings *n* and *m*, of which the inner consists of one piece, whilst the middle one is divided into four

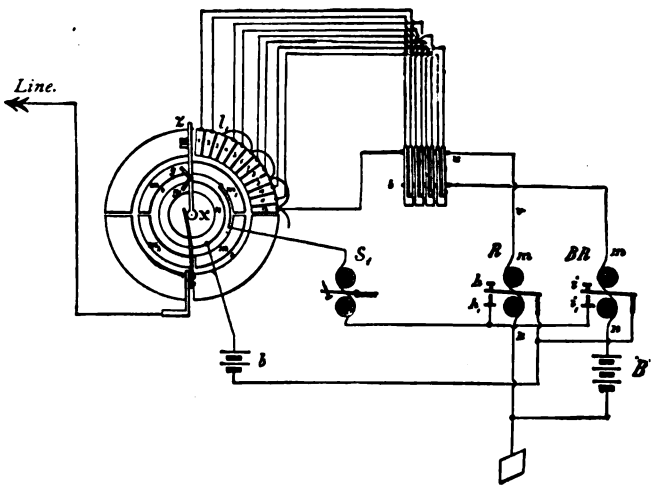


Fig. 794.—Meyer's Connection of Receiving Instruments.

portions, m_1 m_2 m_3 m_4. The fork-shaped brush $g g_1$ is fastened upon the pointer, and one prong of this brush slides over the quadrant *m*, and the other over the undivided ring *n*. One pole of the local battery *b* is connected with the latter, the second pole is connected with the armature lever of the relay R; a wire leads from the contact screw h_1 of this relay to the writing apparatus S_1, which is connected on the other side with the quadrant m_1 of the middle ring. Owing to this connection the action of the apparatus is as follows: The current reaches pointer *x z*, and flows from there over the contact piece 1, then through the key-work *b u* and over *v m n*, through the relay R, to earth. The relay is affected and closes the local circuit for the writing apparatus S_1 by pressing its lever on h_1. The local current passes from *b* over h_1 into the writing apparatus S_1, and then into the quadrant *m*, upon which the brush *g* of the pointer has to be arranged, because the lines of separation of the quadrants of both rings fall in the same radii. From *g* the current reaches g_1, then the ring *n*, and so

flows back again to the battery *b*. By connecting all four quadrants m_1 m_2 m_3 and m_4 with the writing apparatus s_1 s_2 s_3 and s_4, as shown in Fig. 795, four telegrams are received by the writing apparatus, which are separate from each other.

Meyer's Printing Apparatus.—As all multiplex and distinct systems require a special arrangement for the printing apparatus, we shall give an explanation of Meyer's. In the first place, the currents of all four quadrants may only affect one writing apparatus, so that all four telegrams are printed by it.

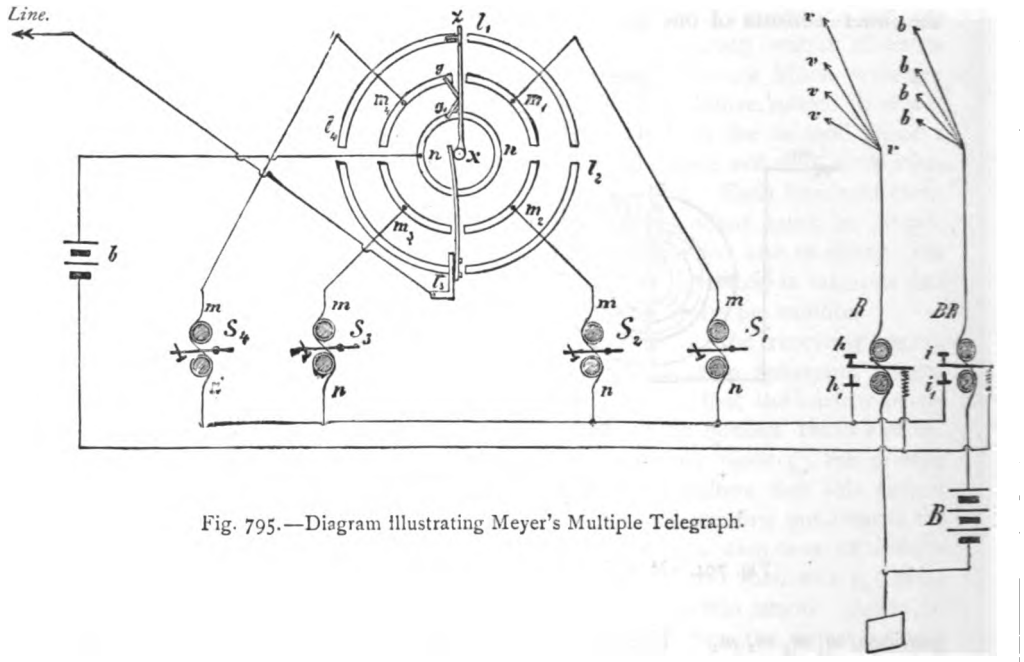


Fig. 795.—Diagram illustrating Meyer's Multiple Telegraph.

Meyer uses for this purpose a thread, *a* K K *e*, as shown in Fig. 796, which surrounds the cylinder z z. The paper strip *p p* is carried by the rod s s, which is in connection with the armature of a magnet. Every time this armature is attracted by the magnet the paper is pressed against the thread upon the cylinder z z; the latter has its axis connected with the apparatus in such a manner that its velocity and that of the pointer upon the contact disc are synchronous. A roller *t*, Fig. 797, furnishes the thread with ink. When now *p p* is pressed against the cylinder, that portion of the thread will produce a sign on the paper which happens to be opposite to it, as, in Fig. 796, the place *d*. If the contact be for a long period, the line *d g* will be produced; if the paper remains pressed against the cylinder during a full revolution of the cylinder, the line $f f_1$ will be produced. As a complete revolution of the cylinder corresponds with a complete revolution of the pointer on the contact

disc, a quarter of a revolution of the cylinder will correspond with the passage of the pointer over one quadrant. The piece I of the thread will, therefore, correspond with the first quadrant, piece II of thread with second quadrant, piece III with quadrant III, and piece IV with quadrant IV. As the cylinder and pointer move synchronously, the following must also take place: The

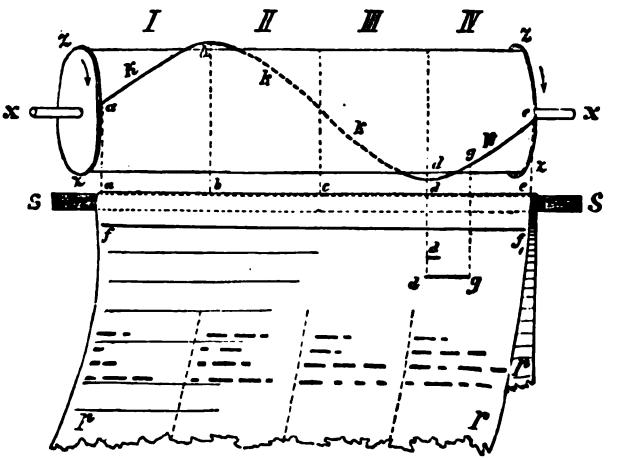


Fig. 796.—Meyer's Printer.

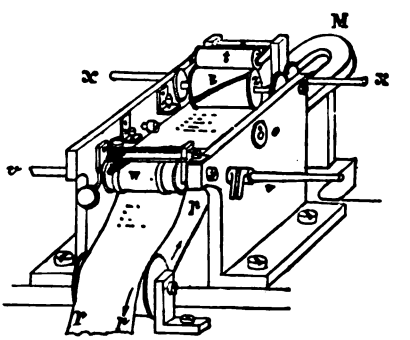


Fig. 797.—Meyer's Printer.

several portions of the thread *a b* must successively be nearest the paper as the pointer glides over the contact pieces of the first quadrant, and, moreover, the pieces II, III, and IV of the thread must correspond to the second, third, and fourth quadrants respectively. The mode of action of the apparatus will, therefore, be as follows: When the pointer has gone over the twelve contact pieces of the first quadrant, corresponding currents have reached the writing apparatus, and at the same time the cylinder has completed the greater

revolution, and has brought the several portions of *a b* in contact with the paper *p p*. During this time the magnet has, by means of its armature, raised the rod s s as often and sustained it as long as corresponded with the arriving currents. The paper will, therefore, have in the first quarter of its breadth all those Morse signs which were to be applied from the sending station, *i.e.* the first character of the telegram sent from the station will be reproduced at the receiving station. The pointer now moves over the second quadrant of the contact disc, and upon the second quarter of the paper appear the first characters of the telegram sent from station II, and so on, until the pointer again reaches the contact piece I of the quadrant I. Meanwhile, the paper has advanced some millimetres, and is ready to receive the second characters of the four stations. Hence, we have in the first quarter of the paper the telegram from the first station, at the second quarter the telegram from the second station, etc.

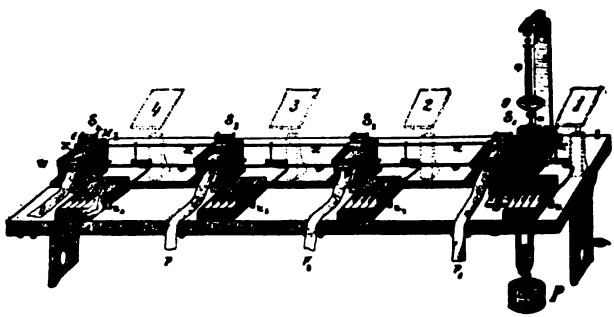


Fig. 798.—Meyer's Multiple Printing Apparatus.

Fig. 797 represents the single printing apparatus of a branch station. M represents a powerful permanent magnet, the armature of which is an iron core, having wire coiled round it. The latter is fastened to a frame that moves about O, one side of which consists of the rod s s, which carries the strip of paper. When the coils are without current the permanent magnet attracts the iron core, and turns the frame in such a manner that the paper is pressed against the thread R of the cylinder Z. When a current passes through the coils it affects the magnet, so that like poles are opposite each other in the permanent and electro-magnets. These poles repel each other, and the frame O is again turned, and the paper removed from the cylinder.

Fig. 798 shows an arrangement of the four printers as four separate instruments. x x is the axis of the printing cylinders, and *v v* the axis of the rollers W, which move the strips of paper in the direction indicated by the arrows. s_1—s_4 represent the four printing apparatuses; each sending apparatus consists of four black and four white keys, and has an alarm arrangement u_1—u_4, which indicates to the attendant when the pointer has reached the quadrant which is under his care. All the branch instruments are worked by means of wheelwork, which is placed at instrument I, and moved by a heavy weight.

CABLE TELEGRAPHY.

Long over-ground lines offer difficulties caused by the electric charges which the wires receive, but these difficulties are still further increased in cable telegraphy. The cable, consisting of copper and iron wires, separated by insulating substances, will behave like a Leyden jar. If the copper wire forming the inner coating receives positive electricity, a corresponding quantity of negative electricity will be held bound by the outer armature surface in contact with the water, and answering to the outer coating. The charging and discharging of the cable, therefore, not only require considerable time, but may also cause indistinctness of signs.

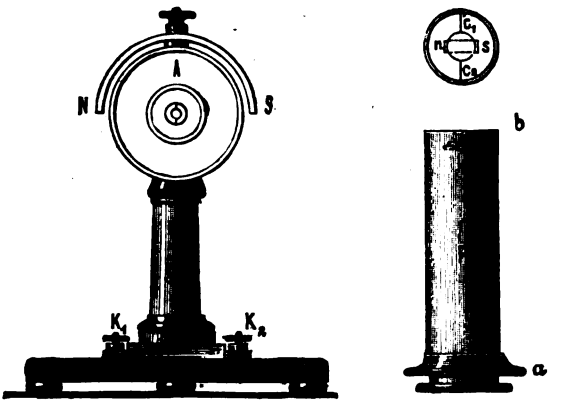


Fig. 799.—Signal Galvanometer.

Special Apparatus for Cable Telegraphy.—If currents of high potential are used, not only are these disadvantages increased, but the insulation becomes much less perfect. Specially-constructed apparatus have, therefore, to be used with cables like the transatlantic. As only very weak currents could be utilised, care had to be taken that the receiving apparatus should possess great sensibility. For this purpose mirror galvanometers have been used.

Mirror Galvanometers.—It is clear that signs may be produced by the deflections of the needle just as with Morse's dash and point. Formerly, therefore, mirror galvanometers were exclusively used for cable telegraphy. A form which is frequently employed is represented in Fig. 799 (Thomson's). The cylindrical bobbin A consists of two coils, which are separated from each other, and each of which has a resistance of 1,000 ohms, so that resistances of 500, 1,000, and 2,000 can be obtained by joining both coils parallel, or by using one coil only, or by joining both coils in series. The copper tube R, which is closed at *a*, but open at the other end *b*, is inserted in the hollow space of the coils, and carries a magnet *n s*, with the mirror at *b*. The mirror

is suspended by means of the cocoon threads c_1 c_2. The bent magnet N S serves to neutralise the attraction of the earth. As it would be rather fatiguing to observe the deflections of the needle through a telescope, a beam of light or picture of a slit in a lamp screen is thrown upon a scale, for which Siemens and Halske have constructed the apparatus shown in Fig. 800. The rays of an oil lamp are allowed to pass through a small slit m_1 m_2, and are then

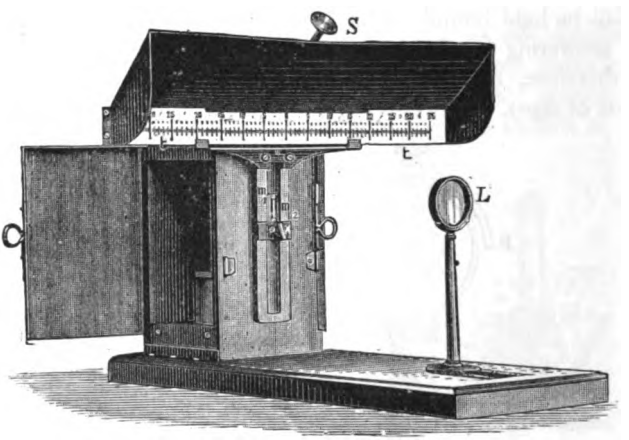


Fig. 800.—Scale for Galvanometer.

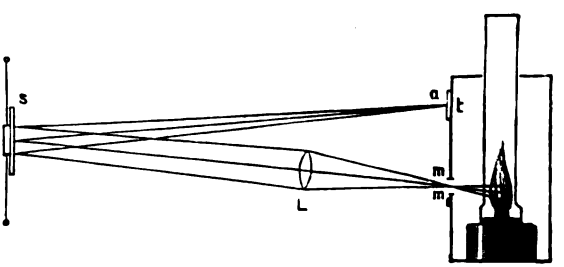


Fig. 801.—Action of the Galvanometer.

collected by the lens L. The slit can be adjusted by means of the screw x. The scale *t t* is fastened at the upper edge of the case, and can be moved along by means of the screw s and a toothed bar. The mode of action of this apparatus in connection with the galvanometer is shown in Fig. 801. The rays of light coming through the slit $m\,m_1$ are thrown by the lens upon the mirror *s*, of the galvanometer, which reflects the rays at *a* upon the scale *t*. The image thus produced falls upon zero on the scale when the coils of the galvanometer are without current, and the image moves to the left or right, according as the needle is deflected to one side or the other. To produce this deviation of the

needle, even with the longest cable, a battery consisting of from 5 to 10 copper-zinc elements is sufficient.

In order to send currents of either direction into a cable, a double tapper (I II, Fig. 802) is used, which consists of two brass springs, I and II, fixed at one end, and having the finger-buttons at the other. The wires from the battery are brought to two strips of brass, one of which (1), connected with the zinc, lies below the springs, but without touching them; the other (2), connected with the copper, passes over the springs, and is in contact with both when they are not pressed down. Whichever spring is pressed down takes the current from the zinc. (*See* Fig. 759.)

The first experiments made with transatlantic cables showed that a new difficulty is encountered when stations that are far distant are connected to earth, that is to say, when the ends of the cable are connected to earth in the usual way, so as to exclude connection of every battery. The experiments showed that

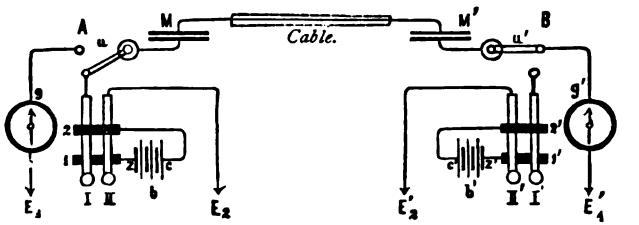


Fig. 802.—Cable Connections.

there is often a considerable difference of potential between distant parts of the earth, which causes earth currents to flow along the cable or leads connecting them. Varley avoided this evil by inserting condensers, to which the cable-ends were connected, and thus avoiding the direct connection of the cable with earth.

The connection of the apparatus at the cable stations, and the joining of the stations, is shown in Fig. 802. From the galvanometers $g g'$ of stations A and B, leads $n n'$ go to earth E_1 E'_1 and to the commutators $u u'$, which, when at rest, have the position shown at u'. Wires lead from the commutators to the condensers M M', the second coats of the condensers being joined to the cable. The necessary currents are furnished by the batteries b and b', the zinc poles $z z'$ of which are joined to the keys I II by means of 1 1', the copper poles $c c'$ to keys I' II' by means of 2 2'. The keys I I' are connected with the commutator, and keys II II' with earth E_2 E'_2.

When A wishes to communicate with B, the commutator is moved from its position as in u', and assumes that shown in u. The negative pole z of the battery is then connected with the commutator u by depressing the key I, and the positive pole c of the battery is connected to earth E_2 by depressing key II. In the former case negative electricity will flow over I_1 and the commutator u to the condenser M, where it spreads over the lower plate, and induces positive

electricity in the upper plate, while it sends a certain quantity of negative electricity into the cable. The negative electricity flows through the cable and reaches the upper plate of the condenser M′, while it binds positive elec-

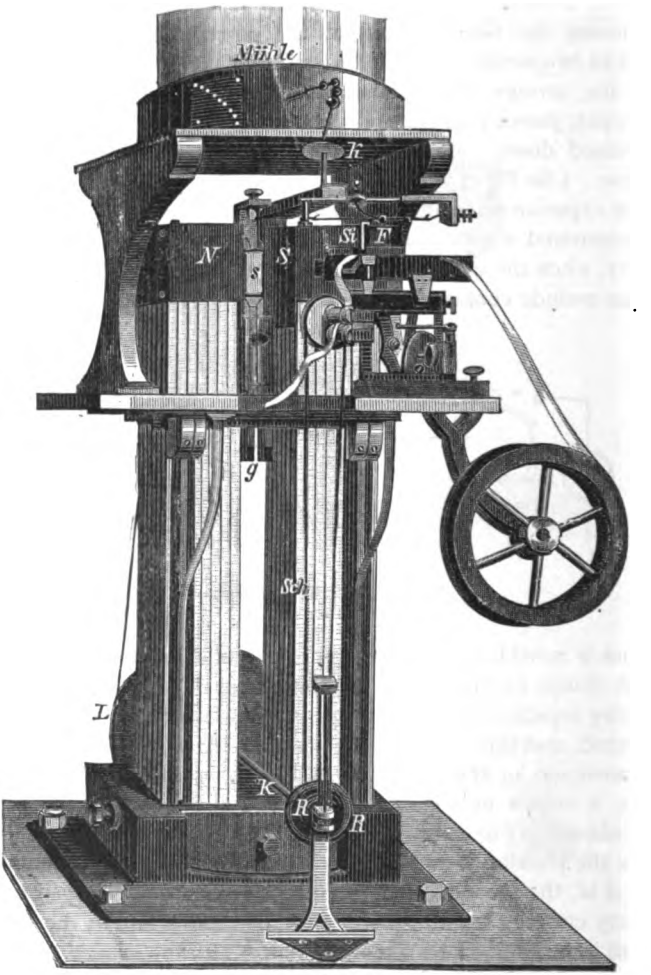


Fig. 803.—Thomson's Siphon Recorder.

tricity in the lower plate, and allows negative electricity to flow through z and the galvanometer to earth E′. The needle is deflected, and the light image moves in a certain direction from the zero point on the scale. A negative current is now being sent through the galvanometer g′ of station B by depressing key I at station A. But when the key is lifted again a positive

current is sent through *g'*. The first current causes the needle to deflect, while the second one brings it back again to its former position. Not more than fifteen to seventeen words per minute can be obtained when galvanometers of the kind above described are used, but other instruments have recently been constructed, such as the siphon apparatus, by Sir William Thomson; the undulator, by Lauritzen; and the soot writer, by Siemens, which permit of a greater speed of signalling.

The Siphon Recorder.—Fig. 803 represents an ingenious and interesting instrument called the siphon recorder, invented by Sir William Thomson. The arms of a powerful magnet, consisting of a number of steel plates, *Sch*, are furnished with the shoes N and S: the wire coils *r r* are suspended between these, and joined to the leads at *x* and *y* (Fig. 804). To make the magnetic field, in which this frame is suspended, more powerful, a piece of soft iron S N is placed inside the frame. The coils are fastened to the cocoon thread *a*, and the cocoon threads *b b* serve to maintain them in a certain position by means of the little weights *g* (Fig. 803). When a current flows through the coils the frame will be turned in one or other direction, according to the direction of the current. This motion will be transmitted by means of the cocoon threads and a lever to the writing arrangement, which consists of the glass siphon s *i*, whose upper arm dips into the ink vessel F; while its other arm, which terminates in a point, marks the strip of paper that is slowly moved past it. A straight line is produced on the paper while the siphon is at rest, but when it is influenced by the electric current, by means

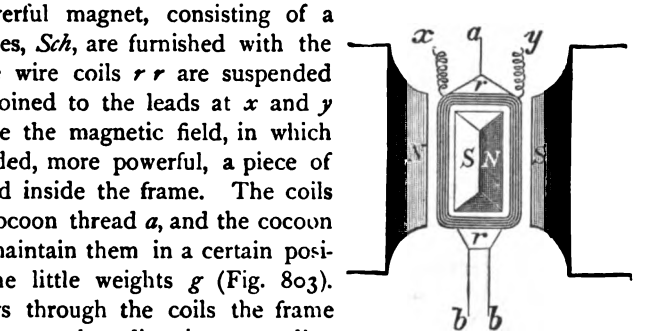


Fig. 804.

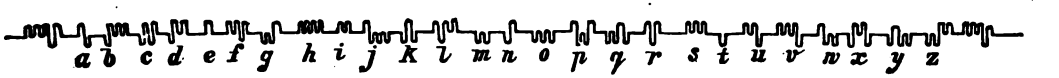


Fig. 805.—Siphon Writing.

of the wire frame, zigzag lines are traced on the paper, which correspond to the direction of the currents which have been sent through. An alphabet has been constructed of these lines, as shown in Fig. 805; before *a* and after *z* are signs which signify "All right," "Understood."

In order to produce distinct marks on the paper, the point of the siphon is made so fine that the ink does not flow from it by capillary attraction alone, but has to be electrified before it can be used; this is managed by means of a so-called mill, which consists of an electro-magnetic motor of the simplest construction, combined with an induction machine. Upon the gutta-percha disc of the latter are metal spokes arranged radially, which have pieces of iron attached to their ends; underneath this wheel is an electro-

magnet, the coils of which have intermittent currents passing through them, which causes the attraction of the succeeding iron pieces, and by this means the wheel is made to rotate. The wheel is surrounded by two semi-cylindrical metal jackets, one of which is electrified in the beginning. When the apparatus is set in motion, induced electricity is generated. The negative pole of this induction machine, as well as the shaft upon which the paper rests, is connected with earth. Electricity enters the ink vessel from the positive pole by means of plate K, and from there reaches the siphon. The fluid in the siphon is, therefore, always positively electrified, while the shaft

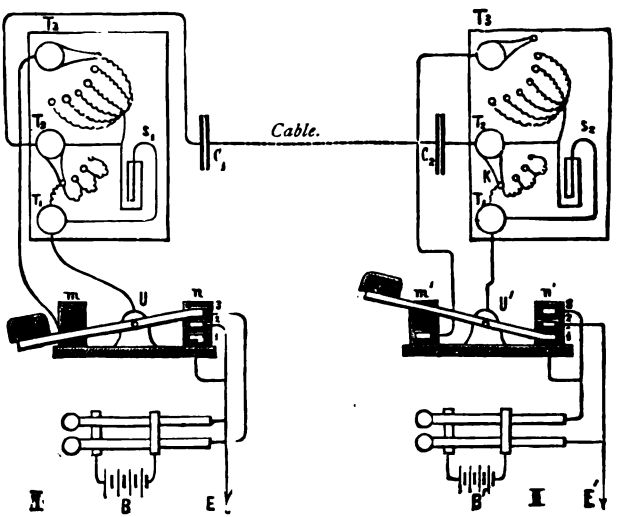


Fig. 806.—Connection of Two Cable Stations.

under the strip of paper is negatively electrified. A continuous current of sparks passes from the siphon point to the paper roller, and takes the ink particles along with it, and deposits them on the paper. The electro-motor also serves to set the wheelwork, which is connected with the strip of paper, in motion.

The connection of two stations having siphon recorders is shown in Fig. 806. The batteries B B', of stations I and II, are connected with double keys, from which the leads run over the commutators U U' to the recorders. The contacts upon the ebonite pieces *m m'* of the commutators are connected with screws T_3. The contacts 1, 2, and 3 of the ebonite pieces *n n'* are connected with the keys and with the earth. The letters s_1 and s_2 indicate the wire frames, and C_1 and C_2 the condensers. When I wishes to communicate with II the commutator of station I is placed upon contact 3 at *n*. By depressing the lower key at station I, a positive current from battery B will take the following way: Through the lower key into the contact 3, and from *n* to U. Here it divides into two

branches: one branch flows from *m* to T_3, the other to T_1, where it again divides into two branches, one of which flows through the frame s_1, while the other flows over the varying resistance T_1 T_2 to the condenser C_1. As the resistance of these two branch currents is considerably greater than the resistance which the branch current encounters at T_3, a current flows through S, which is only just strong enough for recording the telegram to be sent, while the main current flows to the condenser. Between C_1 and C_2 the same phenomena happen as were considered in connection with Fig. 802. A positive current arrives at station II and flows through the frame s_2 over T_1 U′ and the contact 1 of *m*′ into the double keys, and thus to earth at E′, that is to say, a positive current flowing through the frame s_2 deflects the frame in a certain direction, and traces a certain curve on the paper by means of the siphon. When the upper key of station I is depressed, the positive pole of battery B is connected with earth at E, and a current is enabled to flow from the negative pole, over contact 3 to *n*, and so on to the condenser C_1. A negative current will flow from the condenser C_2 through the frame s_2, and will then be deflected in a direction opposite to its former direction, and thus cause the siphon to trace a curve in the opposite direction also.

HOUSE AND HOTEL TELEGRAPHY.

The apparatus used for telegraphy in houses and hotels is of a very simple construction, and usually consists of a key for making contact at the place from which the communication is sent, with a bell and indicator showing either the purpose of the communication or the number of the room from which it is sent. The keys used have frequently the form shown in Fig. 807 in plan and elevation, and consisting of a base A, a cover B, and a plug C. The ground disc A is furnished with the contact springs ff^1, which are fastened by means of screws at *a* and *b*, and overlap, but do not touch at their other ends unless the plug *c* be pushed in. The case B in which the plug *c* is first inserted is screwed upon A, which is furnished with the knob *c*. The springs ff^1 are made of steel or German silver, and are connected with the leads at *a* and *b*. By pushing in the plug the springs ff^1, which are connected in the same circuit with the battery and the bell, are pressed together, and the circuit is closed. The drawing to the right represents a suspended key with the knobs I II III.

When the installation is worked with constant currents, only one spring *f* is fastened to the ground plate *a*, and when at rest it leans against a support fastened at *f*, which is in connection with one wire of the leads, whilst the other wire is connected with the spring. By depressing the knob *c*, the spring is pushed in, and contact with the support ceases, so that the current is broken. The so-called vibrators or tremblers are used for receivers. These consist of bells such as those shown in Fig. 786. The connection of the bell with the key is very simple when it is only required to give a certain signal from a certain place, and when no return message is necessary. One pole of the battery is

connected with one spring of the key, while the line-wire connects the second spring of the key with the bell, the second clamp of the bell being connected with the second pole of the battery. Where signals are to be sent and received,

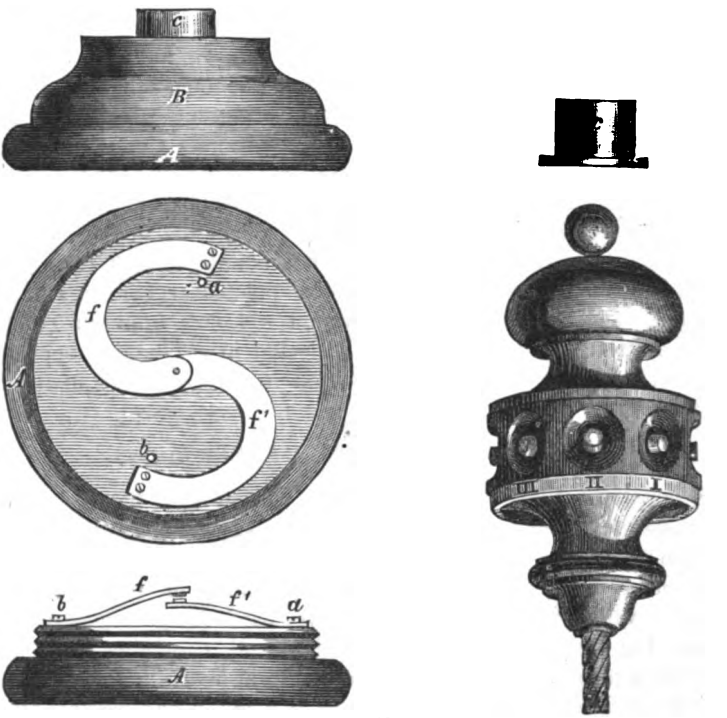


Fig. 807.—Keys.

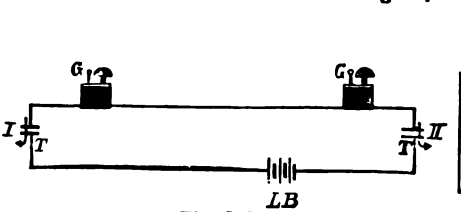


Fig. 808.

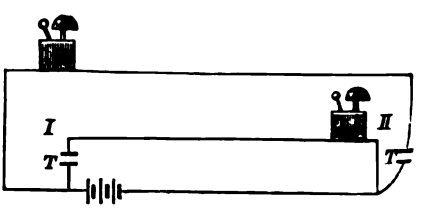


Fig. 809.

Connection of Vibrators.

the connection would be as shown in Fig. 808. T T represent the keys, and G G the bells, which are inserted in the circuit of battery L B. A connection for an intermittent current is shown in Fig. 809.

Different contrivances are connected with the bells in order to show from which room the message has been sent. Fig. 810 represents Bréguet's indicator. The armature A is fastened above the electro-magnet M, by means of the

spring *f*. The catch s consists of sheet-metal, it is movable about *o*, and with its hook *n* hooks on to the end of the armature; it is maintained in its vertical position as long as the magnet is without current, but as soon as a current

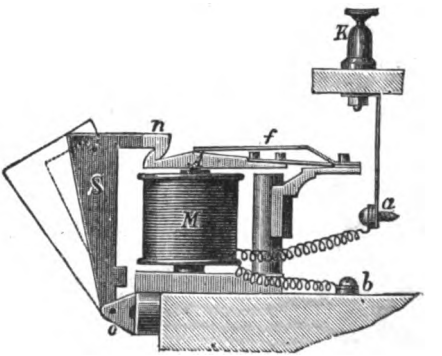


Fig. 810.—Bréguet's Indicator.

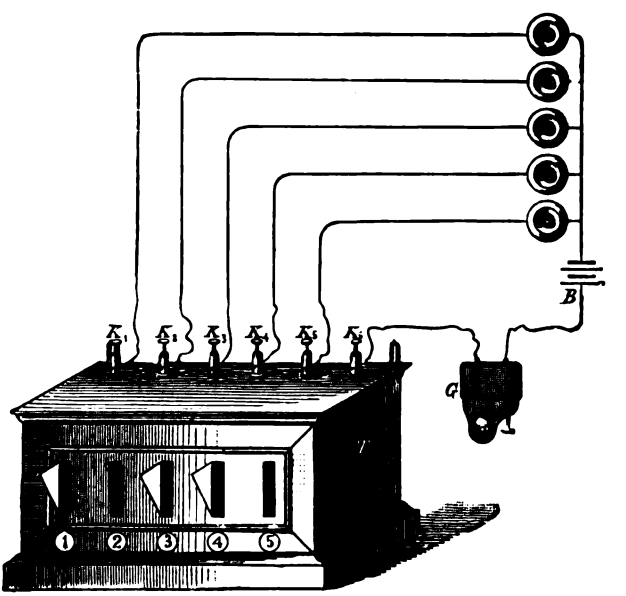


Fig. 811.—Bréguet's Box of Indicators.

passes through the coils of the electro-magnet, the armature moves downward, and s assumes the position indicated by the dotted lines. The indicator box T, Fig. 811, has as many of such pieces of apparatus as there are keys connected with the battery B and bell G. The ends *a* of the electro-magnets are connected with the keys by means of the clamps K_1—K_5. The other ends of the wires

of the electro-magnets lead to clamp K_6, from which a wire leads to the bell G, the second wire of which is connected with one pole of the battery. The second pole of the battery is connected with the second contacts of the keys. If, for instance, the third key is depressed, the bell rings, and at the same time the indicator makes its appearance; the indicator is pushed into its former position again by the attendant.

An indicator having numbers, constructed by Hagendorff, is shown in Fig. 812. The electro-magnet M M is screwed to the wall T of the frame, and its

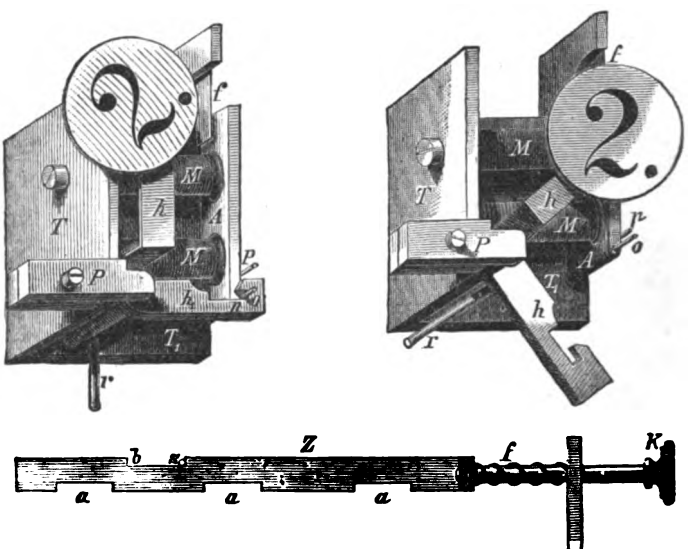


Fig. 812.—House Indicators.

armature A is held back by means of a spring *f*; the bent lever $h\,h_1$ is pivoted to the piece P, and its arm *h* carries the disc with a figure; the disc, when at rest, stands vertical, and is maintained in its position by the pin *o* of the armature, which catches the lever-arm h_1 at *n*. When a current passes through the coils of the electro-magnet, its armature is attracted, and the pin *o* allows the lever to drop down. The lever then assumes such a position that the disc makes its appearance before a little opening in the indicator box. The lever is made to assume its former position again by means of the rod z, the knob K of which is placed outside the right wall of the box; by pulling this knob the rod z moves from left to right, and catches the rods *r*, which are fastened to the lever, with its openings *a a a*. The pin *s*, which is visible in the open portion of the rod z, serves to prevent the rod z from being pulled out too far, and in this task it is further aided by the spring *f*. When not only signs, but whole messages are to be sent, the simplest plan would be to have a double

telephone station fitted up; needle and dial instruments, however, are frequently used for this purpose.

Automatic Alarm Apparatus are frequently used to indicate or sound an alarm under certain circumstances of danger, as when, for instance, a door, window, etc., is opened by strangers, or when the temperature has risen or fallen beyond a certain point, etc. etc.

Door Contacts.—The opening of a door can be indicated by means of so-called door contacts, which are inserted in the circuit of a battery. Two of such

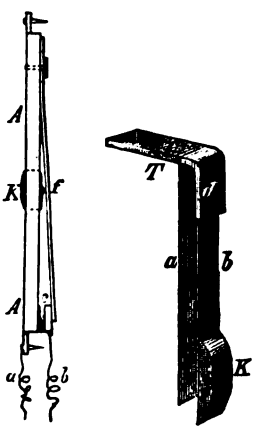


Fig. 813.—Door Contacts.

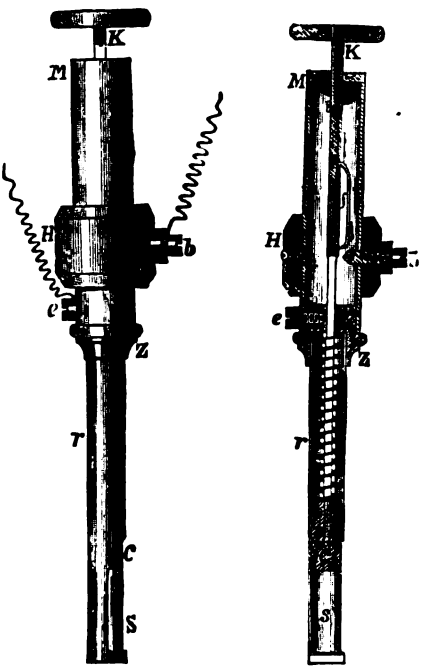


Fig. 814.—Fein's Fire Alarm.

contacts are shown in Fig. 813. The metal plate A A is let into the jamb, so that its surface A A is in the same plane as the surface of the jamb. Inside the plate, which is connected with the leads at *a*, is fastened the contact *c*, which touches a contact *f* when the door is opened; the spring *f* is fastened at the top of plate A A, and from it the second wire leads. As long as the door remains closed, it presses the insulated knob K against the spring *f*, so that contact is broken at *c*. When the door is opened, *f* pushes the knob K out, and makes contact with *c*. The current flows over *a*, A A, *f*, *c*, and *b*, and the bell rings until the door is shut again. When the opening of a door has to be indicated by a short signal, only the contact to the right in Fig. 813 is used. To

the metal piece *c d* is fastened the spring *b*, with its horn piece K. The spring *a* is fastened parallel to spring *b*, and each of these springs is connected with one wire of the leads. The arrangement is fitted to the jamb in such a manner that

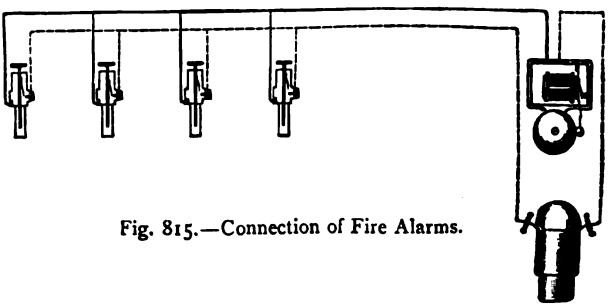


Fig. 815.—Connection of Fire Alarms.

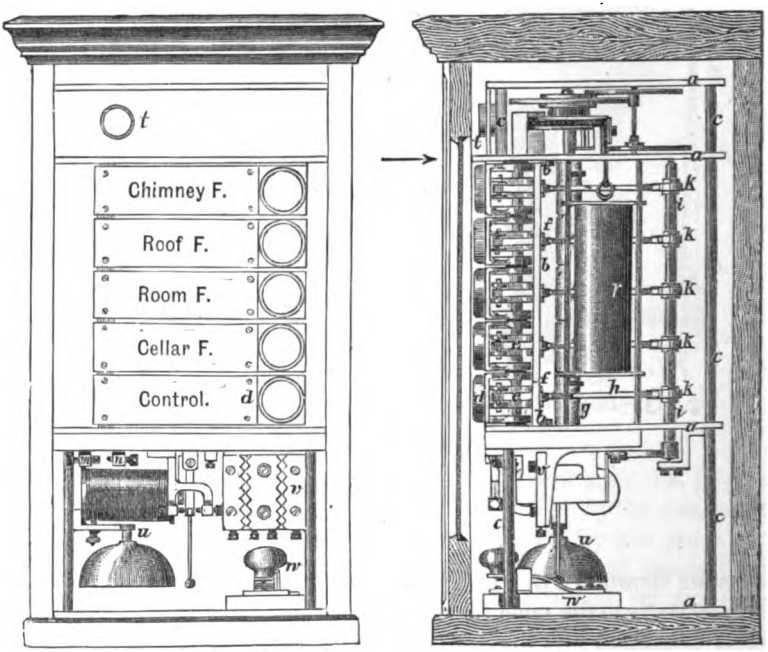


Fig. 816.—Egger's Fire Alarms.

the door-edge, when opening or shutting, passes over the spur-piece K. A bell connected with this contact will ring as long as spring *b* is in contact with *a*.

Fire Alarms.—An automatic fire alarm, which has been constructed by W. F. Fein, the action of which depends upon the fusibility of some alloy, is shown in Fig. 814. The brass tube M has an ebonite ring attached to it at H, through which the contact screw *b* passes, being insulated thus from M; the

tube *r* is fastened to the middle piece z, and a rod passes through both tubes and terminates in a knob K, which presses upon a cylinder S, consisting of the fusible alloy. The apparatus is now inserted in the circuit of a battery; when the cylinder S melts, the rod slides down the tube *r*, and makes contact with the screw *b* and the portions of the apparatus in connection with the spring *f*. Several of these instruments may be inserted in a circuit, as shown in Fig. 815.

Fig. 816 represents an apparatus constructed by B. Egger, of Vienna, by means of which any person may communicate with the central station of a fire brigade. The instrument has five keys: the highest has the words "chimney fire," the next "roof fire," then "room fire," "cellar fire," and "control." At the bottom of the apparatus are placed the bell *u*, a Morse key *w*, and the lightning plate *v*. From the figure to the right we see that the whole apparatus

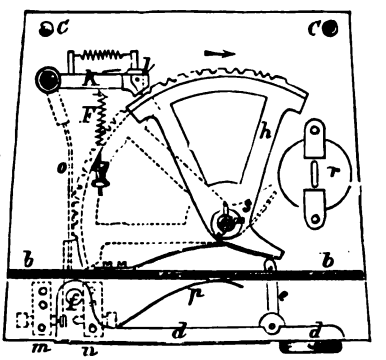


Fig. 817.—Key of the Alarm.

is divided into three portions by means of the four plates *a*, which are supported by *c c* and *b b*. The uppermost portion has a wheelwork, and the middle portion is fitted with the five keys. The arrangement of one of these is shown in detail in Fig. 817. The key *d* which moves about *f* is pressed against the front wall of the box by means of the spring *p*. The key is connected with the arm *e* by means of a joint; the end of this arm rests upon the sector *h*, which moves about *g*. The lever K which moves about *i* stands opposite this sector in such a position that the angular piece *l* touches the periphery. The spring *o* has a platinum contact, which, when at rest, touches the contact screw *m*, and is maintained in this position by means of K, and the spring F. The weight *r*, which moves between guiding bars, sets the wheelwork in motion. When the key *d* is pushed in, the sector *h* assumes the position shown by the dotted lines and lifts the weight *r*. If the key is allowed to assume its former position the lever *e* also goes back into its former position, and the sector *h*, influenced by the descending weight *r*, likewise moves back into its former position. During this motion of the sector the angle *l* has to follow the inequalities of the periphery of the sector, and this causes the lever K and the spring *o* to vibrate, and to make

contact alternately at *m* and *n*. By referring to Fig. 818 it will be seen that the contact *n* is connected with the lever *o* as well as the lever *k*, and therefore it follows that every time *o* touches *n* a current is sent off. These different currents produce the word which is on the key at the receiving station. At the receiving station are arranged a lightning plate B (Fig. 818), a relay R, a galvanometer G, an alarm W, a Morse apparatus M, a key T, the line battery L B, and the local battery O B. When the key W is depressed a current flows from the line battery L B over T, through the galvanometer G, and the relay R, to the plate B, thence through the line to the automatic apparatus, and then through the lightning plate *v* to the contact *n*. As often as the latter comes in connection with the spring *o*, a current passes over the lever *k*, and the

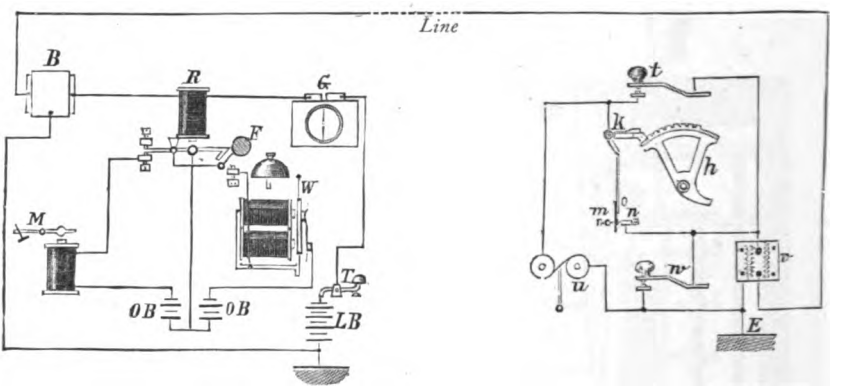


Fig. 818.—Connection of Automatic Fire Alarms.

bell *n*, to earth E, and thus returns to the starting battery, for the second pole of L B is also connected with earth. The current flowing through the relay R closes the circuit of battery O B, and the Morse apparatus M. The action of the relay also causes the key F to fall, whereby the circuit of the bell W is closed. The key T now allows the operator to re-connect the line with the earth, so that a signal may be sent back. As many as 100 of such systems of apparatus were in use in 1881, and they worked in a very satisfactory manner.

ELECTRIC CLOCKS.

Electricity is used in connection with clocks in three different ways: (1) To control distant clocks from one standard clock. (2) To regulate clocks that are independent of each other. (3) As the motive-power. The transmission of time from a standard clock was tried by Steinheil in 1839. Electric clocks have been constructed by Bain, Hipp, Arzberger, Bréguet, Winbauer, and others. Fig. 819 represents an arrangement by Bain. The standard clock is represented by the pendulum D, the wheelwork, etc., being

left out of the figure. This pendulum has a copper spring at D, which glides over the copper plate C once in every second. By means of this contact arrangement the circuit of battery *z k* is closed once in every second. The clocks to be regulated are inserted in the circuit of the battery *z k*, by means of electro-magnets, such as M in the figure. The current reaches the electro-magnets M, and causes the attraction of the armature *b*. A spring *g* is fastened at the lower end of the rod, which carries the armature and also the catch which catches in the teeth of wheel *e*. When the armature *b* is attracted by the magnet M the catch slides over one tooth of the wheel, and the magnet loses its force of attraction during the break of current which follows. In consequence of this the armature is drawn back by the spring *g*, and the catch

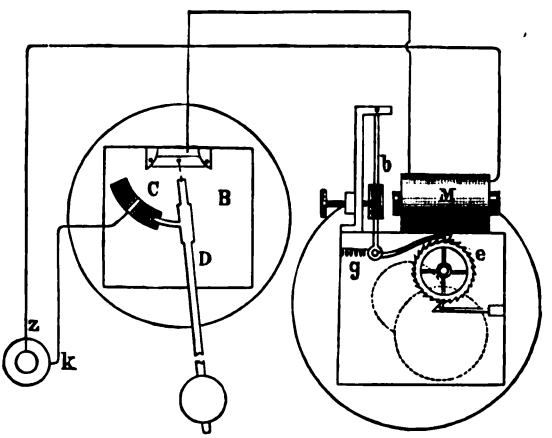


Fig. 819.—Bain's Clock.

moves the wheel one tooth forward. The safety catch fastened at the bottom of the wheel *e* prevents the other catch from going over more than one tooth at a time. Hence, the motion of the clock connected with M is not regulated by a pendulum of its own, but by the escapement attached to *b*, which releases and checks the wheel *e* synchronously with the motion of the pendulum D. The motion of the wheel *e* is transmitted in the ordinary way to the minute and hour wheels.

Bréguet's Lantern Clock is shown in Fig. 820; it possesses two electro-magnets E E, joined in series in such a way that their opposite poles face each other whenever a current flows through the coils. The permanent magnet A A, which is movable about V, is placed between these electro-magnets. The currents are sent through once every minute, and alternately in opposite directions. This causes the permanent magnet to move once to the right and once to the left every two minutes. This motion is transmitted by means of the rod *t* to a system of catches *i i*, which move the wheel *c*, which in its turn moves the hour hand.

The change of current which takes place every minute is brought about by a gyroscope, such as that shown underneath. The ivory cylinder *f g* is fastened upon the axis *t*, which is moved by means of a wheel with ten teeth through a certain angle every minute. The surface of this ivory cylinder is furnished with platinum pins, which alternately come into connection with the upper and the

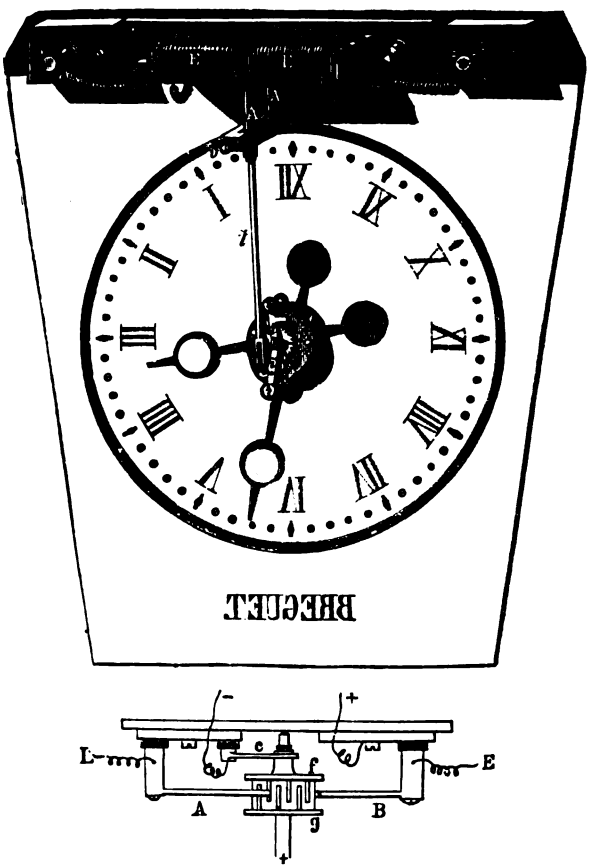


Fig. 820.—Bréguet's Clock.

lower plate. The lower plate is fastened upon the axis *t* without insulation, but the upper plate is insulated from the axis, and stands connected by means of the spring *c* with the negative pole of the battery. The positive pole communicates with the non-insulated metal portions of the gyroscope, and also with the platinum pins of the lower plate *g*. The lines L and E are connected with the contact springs A and B, which slide upon the ivory cylinder. When the spring A is in connection with an upper platinum pin, and spring B with a lower platinum

pin, the current flows from + through the axis *t* and plate *g*, to the lower platinum pin, through the spring A into the line, and then back to the negative pole over E B, and so to an upper platinum pin over *f* and *c*. During the next minute the ivory cylinder has moved so far that the spring A comes in contact with the next lower platinum pin, and the spring B with the upper platinum pin. The current has now to flow in the opposite direction through the line, viz. from + over *t* and B into the line *c*, from which it returns at L, and then passes over A, *f*, and *c*, and finally reaches the negative pole.

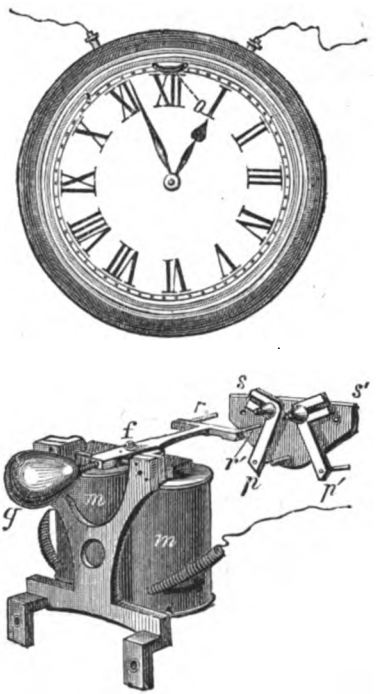


Fig. 821.—Barraud and Lund's Regulator.

Synchronised and Sympathetic Clocks.—By means similar to those just explained, one standard clock, in whatever way regulated, may, by means of magneto-electric currents, convey absolutely isochronous movements to any number of affiliated clocks at any distance. Clocks which possess works of their own, and are only connected between certain intervals by means of electricity, are termed secondary clocks, or when the connections take place regularly every hour, the arrangements for making them are called hour regulators. The hour regulator by Barraud and Lund, which is distinguished by its simple construction, is shown in Fig. 821. The vertical electro-magnet *m m* possesses an armature, which is movable about *f*, and which has the weight *g* attached to one end, and a bar to the other end. This bar terminates in the two pins *r r'*; these pins catch in the slits *s s'* of two movable angular pieces *s p*, *s' p'*. (For the sake of distinctness, *r r'* has been represented in the figure so as not to catch *s s*.) As long as no current flows through the coils of the electro-magnet, the pins *p p'*, which reach through an opening of the clock-face at O, remain at the ends of the circular hole. The minute hand can, therefore, pass under the first pin. When, now, the minute hand is close to twelve, the current is closed by the standard clock. The magnet *m m* attracts its armature, and the pins *r r'*, which slide in the slits *s s*, move the angular pieces, so that their ends cross like the blades of a pair of scissors. The two pins will, therefore, catch hold of the minute hand and place it exactly at twelve. The current is now broken, and the pins *p p'* are drawn again to their former position by means of weight *g*.

Hipp's Connecting System is represented in Fig. 822. The plate *n*

carries the vertically arranged electro-magnet o_1, the armature p_1 of which is movable about the fulcrum q_1. The hook r_1 of the armature lever holds the lever s_1, which is movable about the fulcrum t_1, in the position shown in the drawing, as long as no current flows through the coils of the electro-magnet. The lever s_1 has at u_1 a block with a V-shaped incision, and the wheel x_1 has a pin attached to its front side at v_1. When the armature p_1 is attracted by the electro-magnet o_1 the lever s_1 is released, and the block u_1 falls upon the pin v_1, then the wheel x_1 is moved a little forward or backward, according as the clock is fast or slow, and the hands are thus made to mark twelve o'clock exactly. The block u_1 is so cut that it can catch the pin when it is as

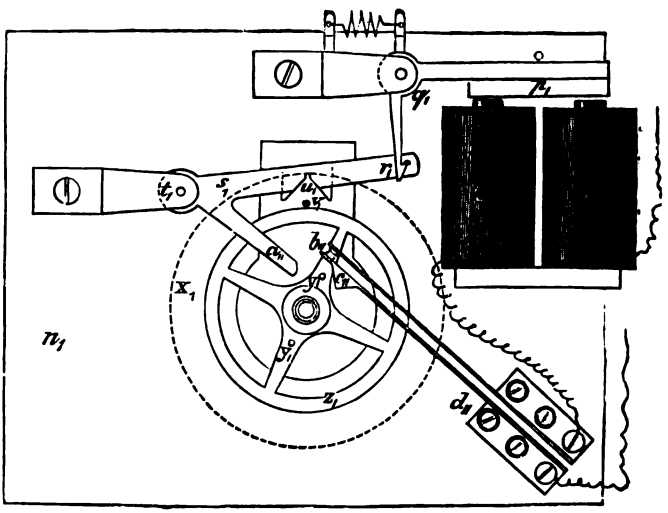


Fig. 822.—Hipp's System.

much as five seconds before or behind time. When the pin y_1, which is fastened upon the hour wheel z_1, comes under the projection a_{11}, the lever s_1 is brought into its former position again. A regulator, which furnishes a current at regular intervals, is used as a standard clock. If the current is required to act only every six hours, the two contact springs b_{11} and d_{11} are inserted in the circuit. The current therefore will only reach the coils of the electro-magnets when the two springs touch each other at b_1. This happens only twice during the complete revolution of the hour wheel, that is, when one of the two pins $y_1 y_1$ presses against the projection c_{11} of the spring d_{11}. This system is chiefly intended for the regulation of electrical clocks which are furnished with pendulums, and for translation regulators for clocks connected in an extensive network.

Hipp's Electrical Clock Pendulum is shown in Fig. 823. The pendulum has a peculiarly constructed armature, which is designed to make the current

in an electro-magnet only when it is required. When the arc of oscillation diminishes beyond a certain mark, the circuit of the electro-magnet is closed, and the armature at the lower end of the pendulum is attracted, and gives a new impulse to the pendulum. The current, of course, has to be broken before the armature comes opposite the poles of the electro-magnet, that is to say, before the pendulum passes the vertical and the armature begins to leave the magnet. The break and make of the current is managed in the following manner: The prism *d* is fastened on the pendulum rod, about the middle of

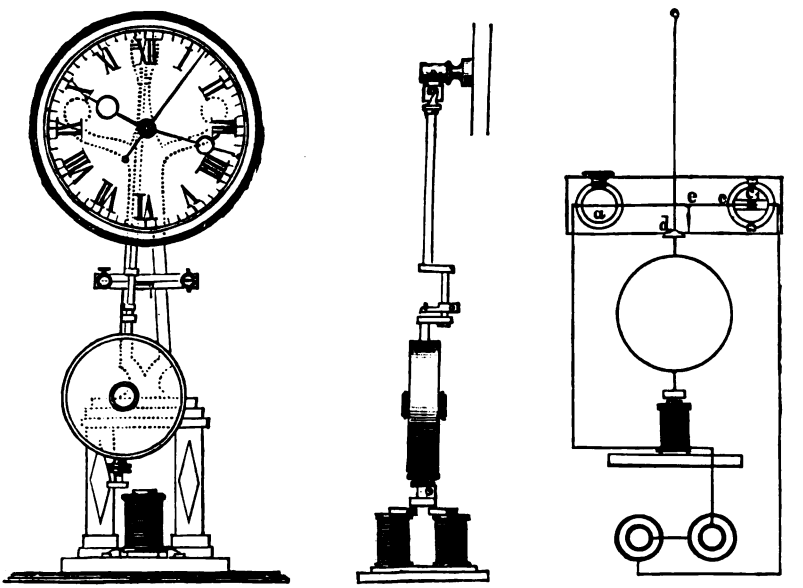


Fig. 823.—Hipp's Electric Pendulum.

its total length; *c* is a spring, one end of which is fastened at *a*, while the other end is free, and rests upon an agate point at c_1, and a little steel plate, called the "palette," is suspended from the spring *c*. Above it is a screw which is connected with one pole of a battery, while the other pole is connected with the spring *c*. The current is made, and the electro-magnet is excited every time the spring *c* touches the upper contact at c_1. The pendulum rod and the palette *e* are in the same vertical plane, and in order that it may be able to oscillate, the pendulum rod is arranged at this point, as shown in the figure, that is to say, it is bent at right angles. As long as the arc of oscillation is sufficiently large, the prism passes underneath the palette *e*, and the spring *c* remains upon the agate point; but when the arc diminishes *e* catches in a groove of the prism, and lifts the spring *c*, thus making contact at c_1, and closing the circuit. The magnet then attracts its armature, and

gives a new impulse to the pendulum; when the latter moves on under the influence of this new impulse, *e* slides down again from the prism *d*, and breaks the current. The attraction of the magnet now ceases, and the pendulum

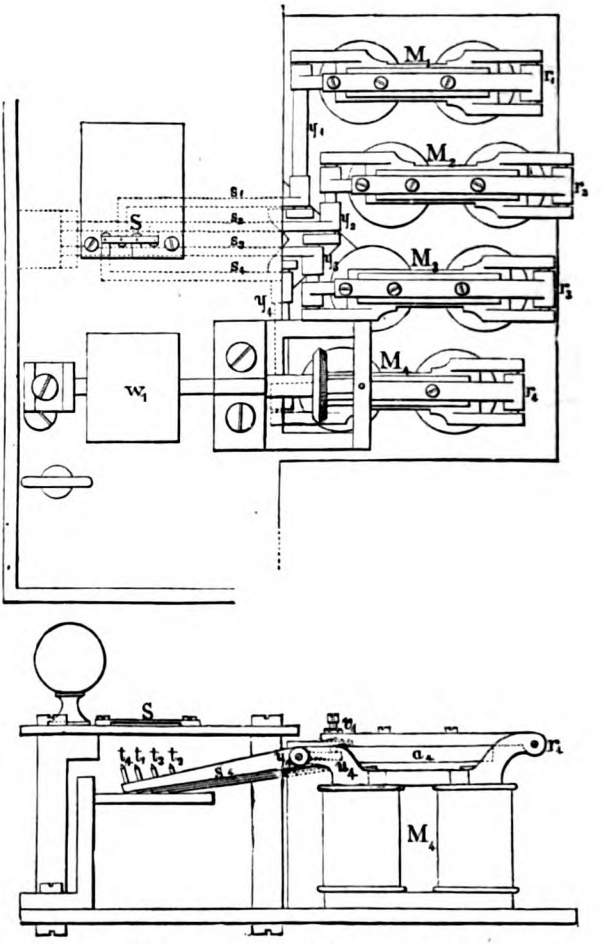


Fig. 824.—Hipp's Watchman-Clock.

continues to oscillate. The number of times the current is made during a certain time depends upon the strength of the battery and the resistance of the electro-magnet. Doppler observed that when two newly-fitted Leclanché elements were used, at first the current was made every forty seconds, but after some months it was made every twelve or eighteen seconds, without the clock showing any irregularity.

Electrical Watchman-Clocks are used to show whether the watchman of a factory, theatre, etc., really makes his rounds at the appointed time. These control clocks consist in principle of a clock which keeps good time connected with an electrical registration apparatus. The watchman causes the time of his passing to be registered by depressing the keys which are arranged at certain places on his beat.

The apparatus constructed by Hipp for this purpose is shown in Fig. 824. Let us suppose that the apparatus is intended for four controlling places. In the lower portion of the clock case are the four electro-magnets M_1 to M_4, each of which has a movable armature; M_4, for instance, has the armature a_4 which moves about the fulcrum r_4. This armature is adjusted by the screw v_4, which rests with its point upon the two-armed lever s_4, which is movable about a fulcrum at y_4. By depressing the key of the electro-magnet M_4, the magnet is made to attract its armature a_4, and thus to depress the short arm u_4 of

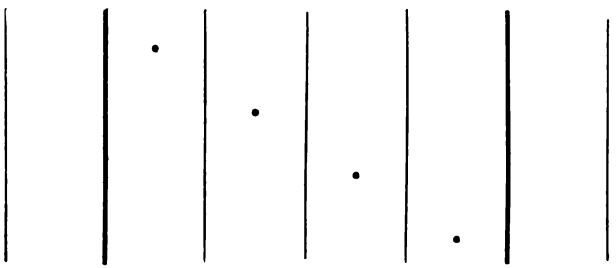


Fig. 825.—Register of the Clock.

the lever. The other arm s_4 is, therefore, raised, and the pencil t_4 that the lever carries is pushed through the slit which is above it. The writing levers belonging to the remaining electro-magnets are bent in such a manner that their pencils may be pushed through the slit s parallel to each other. Above the slit moves a strip of paper, the breadth of which depends upon the number of electro-magnets or controlling places. The paper is kept in motion by the wheelwork of the clock. When the watchman makes his rounds at the time arranged, he depresses the different keys, and by this means marks the paper. To determine the time at which the marking took place, the paper strip is ruled with thin and thick cross lines; the former indicate quarters of an hour, the latter hours. A round of an hour, during which four stations have to be visited, would show the marking represented in Fig. 825.

Electric registration clocks are intended to allow an observer to register the instant of an event occurring. In one form of this clock the observer starts the apparatus at a given time, and thus puts a strip of paper in motion as in Morse's telegraph. A dot is then imprinted on the paper every second by means of a simple connection with an astronomical clock, or the paper is ruled for hours and minutes and wrapped on a roller turned by the clock. A separate marking

apparatus, under the control of the experimenter, by simply making contact by pressing in a key, enables him to interpolate a dot or mark corresponding to the instant of any event happening—such, for instance, as the transit of a star. This method has the advantage of leaving the observer at entire liberty to watch the object without having to attend to the beats of the clock, whilst it renders mistakes next to impossible. It has been successfully applied to the determination of longitudes, and more recently to all kinds of astronomical observations, by Mr. Bond, in America, and by Sir G. Airy, at Greenwich.

Electric chronoscopes are instruments for the measurement of excessively short intervals of time, such as the flight of military projectiles, and even the transmission of sensation and motion along nervous fibres. Such instruments have been constructed on a great variety of principles. Those of M. Pouillet, Mr. Wheatstone, and Mr. Siemens deserve especial mention.

RAILWAY SIGNALLING.

Railway Station Signals.—Fig. 826 represents an arrangement of bell-signals, called the "Double-bell;" G_1 and G_2 are two bells; H_1 H_2 the hammers belonging to them. Each hammer is pressed towards the bell by a spring *f*, but is prevented from touching it by a more powerful spring F. The hammers move about the pivots X_1 X_2. When the wire z is pulled, and then suddenly let go again, the weight of the hammer overcomes the spring *f*, and strikes against the bell; it cannot rest here, however, because it is immediately lifted off by the more powerful spring F.

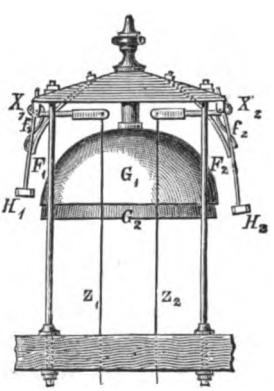


Fig. 826.—Double-Bell.

The wires z are connected with clockwork. The clockwork frequently used in France and Austria for line-signals is that by Leopolder, shown in Fig. 827. The motive-force is supplied by a weight which causes the shaft T to revolve by means of the rope *t*. The wire that communicates with the bell is fastened to the arm z of the lever $z z_1$, the arm z_1 of which is lifted by the pins *r* of the wheel R whenever the catch is pulled back, so as to liberate the wheel. This is effected by means of currents sent into the coils of the electro-magnet M M and a system of jointed levers H_3 N and *c*. The armature A is fastened to the shaft X by means of *h*, and when it is attracted the shaft X moves through a small angle, and with it moves also the angular piece G, which is fastened upon it. This releases the spur *e*, which rested on G, and consequently *e* falls between *p* and *q*, and H_3 catches with its pin *y* the lever N, which moves about O. The projection *c*, which rests upon *n*, is connected with the spiral springs *f* and *w*; the fan W rests upon shaft *u*, which is connected with the remaining wheels of the clockwork by means of a toothed wheel. When, therefore, *c* loses its position upon *n* in consequence of the magnetic attrac-

tion of the armature, the axis of the fan, and with it the whole clockwork, is set free, and the signal is given. The clockwork is stopped, when the current is broken, in the following manner: The shaft a_1 is moved by the wheel R_1 in the direction indicated by the arrow, and lifts the pin of the lever H by means of its own pin *d*; H_1 is also lifted, and *e* is again placed upon the plates *p* and *q*. The motion of the lever H is transmitted to H_3 and the lever N, and *c* again rests upon *n*.

As the signal line has frequently to be utilised for correspondence by

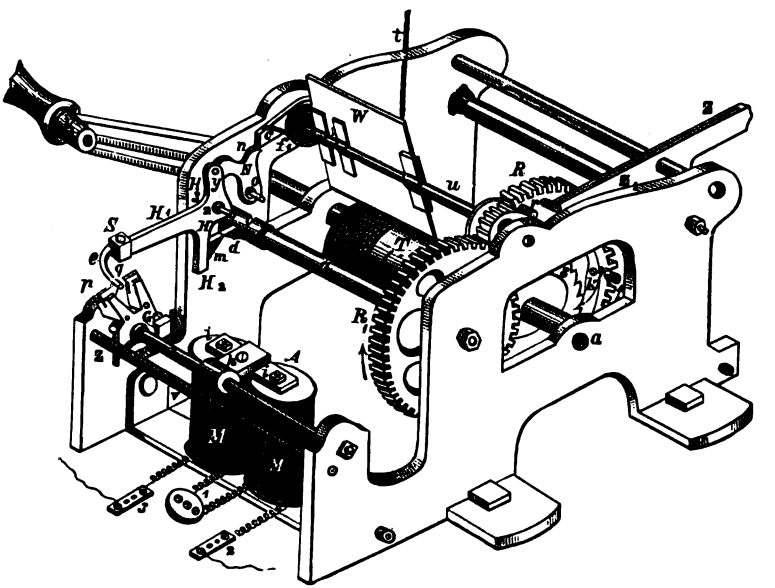


Fig. 827.—Leopolder's Signal Clockwork.

means of a Morse apparatus, the connection of the different instruments with each other and the line has to be arranged accordingly. As an example of such a system of connection, we may take that of the Austrian North-west Railway. The lines of the signalling apparatus have constant battery currents flowing through them, and are connected with the earth at almost every station. When a current arrives at the station by the line L_1 in Fig. 828, it will take the following direction: Through the lightning plate P into the signalling apparatus N, through the key S into the relay R, thence over the key T and the galvanometer G to earth. The commutator *e d i* is connected with the relay R, and is generally so arranged that it closes the circuit of the local battery B_1 over the alarm W. When it is intended to correspond, the local circuit is closed, and this has the effect of inserting the writing apparatus M. The relay remains permanently inserted in the circuit before it acts; the spring of the relay armature

has such a tension that the relay does not require the current to be completely broken, but lets go its armature when the current is only weakened. The springs, however, of the bell apparatus N N_1 have only a very feeble force of attraction, so that the magnets let their armatures go only when the current is completely broken. The keys T T_1 are so arranged that by depressing them the current is not broken, but a resistance is inserted in the circuit, so as to reduce the strength of the currrent. Hence, the mode of action of the total arrangement is as follows: When the Morse key T of a station is used in the

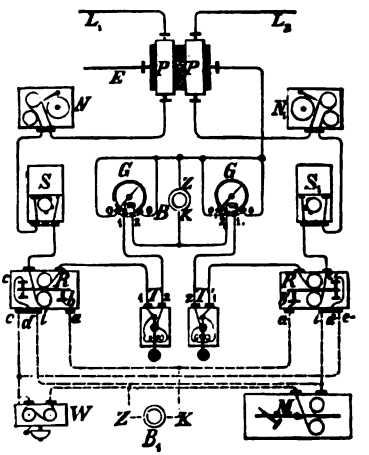


Fig. 828.—General Scheme of a Station.

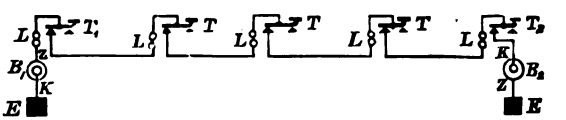


Fig. 829.—Connections of Signalling Instruments.

ordinary manner the line currents are weakened, and have no effect upon the armatures of the magnets of the bell apparatus, but affect the relay R of the second station, and the message sent from the first station is reproduced by means of the writing apparatus M. When, however, by means of the automatic key S, the currents are broken, all the signalling apparatus of that line is brought into action.

Several methods have been suggested by means of which the several signalling instruments on a line may be connected. The method of joining most frequently used to secure a constant current in the line is shown in Fig. 829; L indicates the signalling apparatus; B_1 and B_2 the batteries. The battery B_1 has its zinc pole Z joined to the line, and the battery B_2 its copper pole K, so that these batteries and the inserted apparatus have a constant current circulating through them when at rest.

Railway Carriage Signals.—A second class of signals are the so-called Intercommunication Signals. These are intended to enable passengers or the guards of a train to communicate with the engine-driver. Fig. 830 represents the joining of such a system of signalling by Preece and Walker. Each guard's van has an alarm W, a battery B, and a key T, and every other carriage has a key U. Well-insulated cables, L E, run through the whole length of the train, one of which is connected with the positive poles of the batteries, the other with the negative poles. As long as no key is depressed, no alarm can sound, because the effects of the currents from the two batteries neutralise each other in the coils of the electro-magnets. The bell rings, however, whenever the two cables L and E are short-circuited by depressing a key. This method allows the train officials to com-

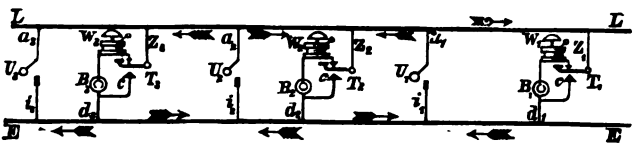


Fig. 830.—Railway Passengers' Communicators.

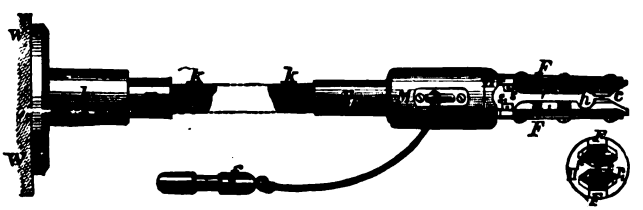


Fig. 831.—Connection between Carriages.

municate with each other. To prevent misuse of the keys by passengers, the keys in the carriages are covered by glass plates, which have first to be broken before the key can be touched, and the key can only be made to assume its former position by another key specially constructed for the purpose. The connection of the cables between the different carriages is shown in Fig. 831. K is the cable consisting of two wires, r is a gutta-percha tube, and h is an iron tube, which is connected with the wall w w of the carriage. The end of tube r_1 has a metal tube M, into which the cylindrical gutta-percha piece H is fitted. The latter carries the two steel springs F F, with their prismatical brass pieces m m, which are furnished with gutta-percha plates p p_1 and platinum contacts at c. The ends of the cable are fastened to the brass prisms by means of the screws s s_1. When the two steel springs F F press the brass prisms against each other, the latter make contact at C, and, therefore, connect both the line-wires with each other. If, now, a similarly constructed catch of a second carriage is pushed into the first, the brass prisms press each other asunder and break contract at C, but one brass prism of the one catch presses against a brass prism of the other, and by doing so connects the wires of two carriages with each other, whilst the gutta-

percha plates $p p_1$ prevent short-circuiting. To prevent a short circuit at the last carriage, a gutta-percha piece f is placed in the catch in order to keep the brass prisms asunder.

Line Signals.—Another kind of signal is the so-called distance signal, where two signs only are required, viz. "line blocked" and "line clear," which may be of an optical or acoustical nature. One of the oldest optical signals, and one still frequently used in Austria, is that by Schönbach. The signalling body consists of a disc with radial openings, and its normal position is parallel to the line and indicates "clear," while the position at right angles to the line (across) indicates "blocked." During the night lanterns with differently coloured lights indicate these positions. The liberating arrangement of the clockwork when at rest is shown in Fig. 832. The lever H rests with its nozzle *e*

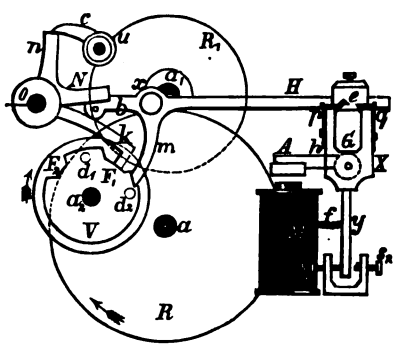


Fig. 832.—Schönbach's Distance Signal.

upon the palette *p*. When, however, a current is sent through the coils of the electro-magnet M, the magnet attracts its armature A and turns the lever *h* together with the fork *g*, so that the nozzle *e* sinks between *p q*. The lever H now moves about its pivot *x* downward and lifts the arm N by means of the arm *b*. But the arms *n* and *k* will also turn with N, and thus set the fan and also the wheel F_1 free from *k*; that is to say, the clockwork will be liberated. The disc now moves through an angle of 90 degrees. Before this motion is quite completed, however, the pin d_1 of the disc V reaches the arm *m* and lifts the lever H to the palette *q* again, while *k* falls in with F_2 and *n* catches the arm C of the fan, and arrests the clockwork. The signalling disc is moved from the position which means "blocked" into the position which means "clear" by turning the key to its former position. The current is thus broken and made, and the clockwork is liberated in the way described. The arresting of the clockwork is not brought about by means of pin d_1 after the disc V has moved through 270°, but by means of pin d_2.

The Electric Steam Whistle.—During fogs, snow-storms, etc., the line signals are hidden from view, and therefore, in addition to the optical signals

already described, acoustical signals are frequently used. Several French railways use the electric automatic steam whistle constructed by Lartigue and Digney Frères, and shown in Fig. 833. P on the left is the steam whistle, the valve of which is connected with an electro-magnet E on the right by a system of levers. Steam can only be admitted to the whistle P from the tube R, through the valve *d*. The valve rod is fastened to the arm of the lever H, and the latter is connected with H_1 by means of the rod *v*. The armature of the Hughes magnet M E is attached to H_1 at A, and it remains in the position shown in the figure as long as no current flows through the coils E of the Hughes magnet, and when this is the case the valve *d* remains closed; but the valve is opened when a

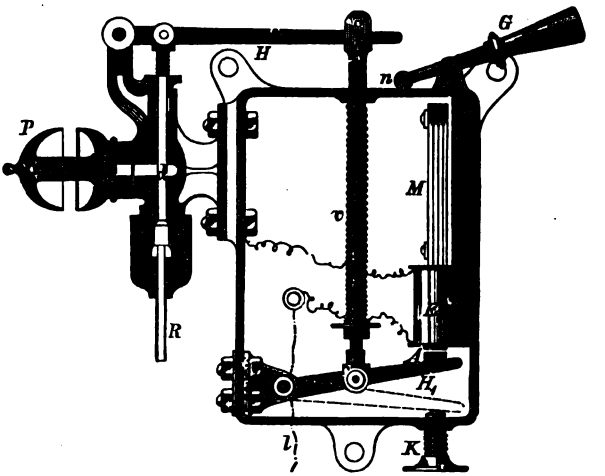


Fig. 833.—Electric Automatic Steam Whistle.

current flows through the coils E, and the armature A is forced off by means of the spiral spring coiled round V. The whistle is silenced by pushing the knob K, which lifts the lever H_1, or by lowering the lever G *n*, which causes *n* to lift the lever H. In this case the armature A is brought so near the magnet that it is attracted, assuming, of course, the current has meanwhile been broken.

The connection of the automatic steam whistle on the locomotive, with the distance signal, is shown in Fig. 834. One end of the Hughes magnet of the whistle P has leads attached, which are joined to a copper brush, which is insulated and hangs below the engine at *a*. The other end is connected with the metal of the locomotive, that is to say, it is connected with the rails, and, through them, with the earth. A contact M N is arranged at a convenient distance from the distance signal, which consists of a wooden sleeper placed lengthwise, and covered with thick sheet copper. The copper is connected with a contact arrangement C of the signalling disc S, by means of the insulated leads L. The other pole of C is joined to L_1, which goes to the battery and thence to

earth. The contact arrangement is such that when the distance signal stands on "stop," contact is made between L and L'; but contact is broken when the signal stands at "free." As soon as the engine has passed the wooden piece Q, when the signal stands at "stop," the copper brush *a* comes into contact with M N, and closes the circuit. The current passes from B over L_1 to the contact C and L, and thence through the contact *a* to the electro-magnet of the whistle, then through the metal of the locomotive to earth, and back through E to B; the steam whistle then begins to sound. When, however, the signalling disc is in the position indicating "free," the contact at C is broken, and the whistle cannot be made to sound when the brush *a* is passing the contact M N.

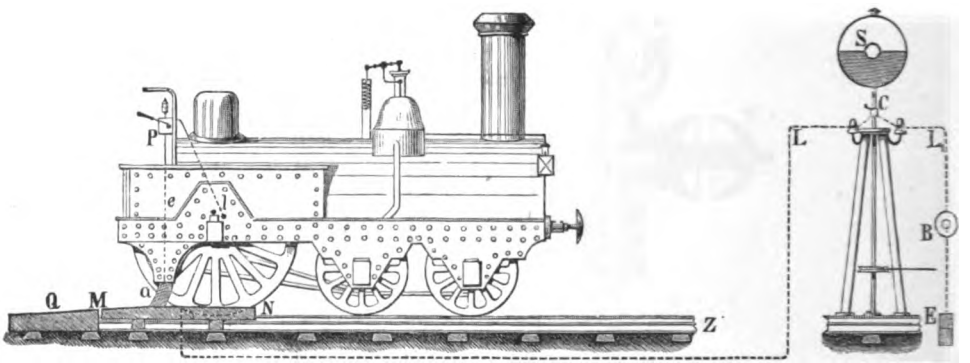


Fig. 834.—Electric Automatic Steam Whistle.

The signal system which has been devised by Putnam, and is made use of in America, has also been tried in Austria. Its essential parts consist of a signalling apparatus, which is contained in a box. Its arrangement is shown in Fig. 835. M is the electro-magnet, with its armature A, which is fixed to the engine. The armature, the arm H, which carries the signalling disc, and the hammer K of bell G, are movable about the same pivot *x*, while the spring *f* sustains the hammer K, and the ball Z, fastened to the hammer by means of a string, opposes its weight to the tension of the spring. When a current flows through the coils of the electro-magnet, and the armature is drawn near the magnet by means of the string and weight Z, it is held fast by the magnet. This position indicates that the line is free, and the signalling disc S remains within the box, that is to say, it is invisible. When, however, the coils of the magnet are currentless, the armature falls off, and the lever system assumes the position shown in the figure. The signalling disc is pushed outside the box, and the bell rings. The bell-strokes are repeated in consequence of the vibrations of the locomotive, because the spring *f* pulls the hammer upward, whilst the ball Z pulls it downward. In this manner the engine-driver receives the signal which tells him to stop. The working of the signal may be better understood from

Fig. 836. The leads L_1 (Fig. 835) are conducted to the metal brush P, which is in front of the locomotive (Fig. 836), and thence to a pole of a small electric machine which is worked by the locomotive; from the second pole of the electric machine a wire leads to the brush P_1 or to the metal portions of the tender. The line is divided according to the amount of traffic into distances of three to five kilometres, and at each point of division a portion *c* of the rails is insulated. The contact brush P slides over the rails, and at each point of division an apparatus is placed which consists of electro-magnets M and M_1, and a lever H which bears an armature, and which is movable about a pivot *x* between the two magnets and between two pins, a contact pin *s*, and a stop pin s_1. When

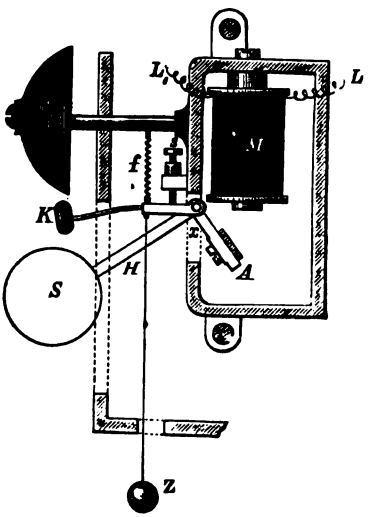


Fig. 835.—Putnam's Signal.

the lever *x y* lies against S, the length of rail *c* is in electrical connection with the rail S; but when the lever lies against s_1, the connection is broken at *y*. The connection *s* of the apparatus at the several division points is shown in the figure. When a train moves from section I to section II, and the brush P_1 slides over the insulated rail *c* in II, whilst the brush P glides over the non-insulated rails S, between II and III, the following circuit is closed: From the brush P over the rail S between II and III, through the apparatus of section I and electro-magnet M_1 of section II, and then through *s* and *c* to P_1. The magnet M_1 now attracts the armature, and places the lever *x y* of the section II upon the insulated pin S_1. When the train reaches from section III to section IV, that is to say, bridges over the gap between the insulated rail *c* at III and the insulated rail S leading to IV, the following circuit is made: Through the contact brush P to *b* and the leads L_3, the electro-magnet M of section II, the

leads L_4, the electro-magnet M_1 of section III, S, *c*, and P_1. The magnet M of section II attracts the armature, and lays the lever *x y* at II on the contact-pin S, while the electro-magnet M_1 of section III lays the lever *x y* upon the insulated pin S_1. The train travels entirely on S between III and IV, and short-circuits its signalling apparatus over P_1, *s*, and P. If, however, a second train passes from III to IV whilst the first train is still between III and IV, the circuit in the signalling apparatus of the second train is broken at the moment when the brush P reaches *c* of III, while the brush P_1 touches *a* at III, because the leads over *x y* only reach to the insulated pin S_1. The signalling apparatus of the second train is, therefore, affected in the manner already described, and

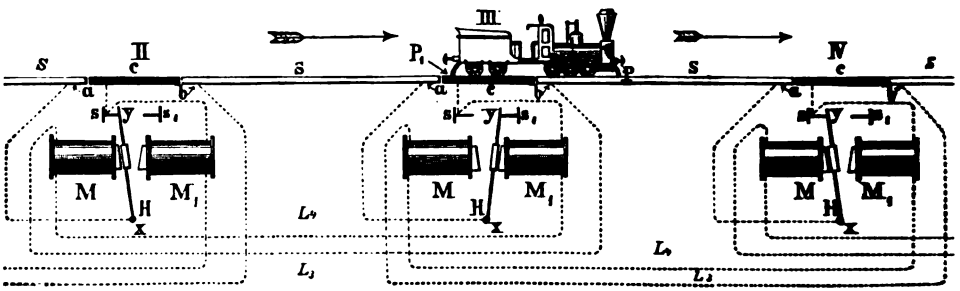


Fig. 836.—Putnam's Automatic Signal System.

the signal "stop" is given. The circuit of the signal of the second train will be closed again when the first train has passed the insulated portion of IV, because by doing so a current is sent through the leads L_3 L_4, between III and IV, to the magnet M of III, causing the lever *x y* to be laid upon the contact-screw *s*.

Any system of signalling in which the apparatus has to be carried by the train has many drawbacks, and stationary signals are generally preferred in England. When trains run very frequently, the distances between every two stations have to be divided into a corresponding number of sections, and each subdivision must have a means of showing the stop signal, so as to detain the train until the obstacle to its further progress is removed. Such an arrangement of signals is known as the Block system. The usual signal is a bell very similar to that shown in Fig. 786.

CONCLUSION.

With these methods of automatic signalling, we propose to conclude. Although it will be seen that we have collected an immense fund of information bearing on the applications of electricity, yet so rapid is the progress of discovery, and so numerous are the workers in this field of investigation and enterprise, that we cannot hope to have included all inventions that might claim a place in our record. We have, however, succeeded in showing how electricity has become one of the most important physical agents of civilisation, and applicable to a great number of the conveniences of daily life. It is an agent at the same time most sensitive and most powerful. Its sensitiveness is shown in the delicate action of the telephone and microphone, and its great power in the giant motors of the day. It has rendered great service in medicine and surgery, and its searching qualities and powers promise for it in these sciences a far wider use than has hitherto been secured. There is no industry that may not profit by its aid, and no art with which it may not possibly be connected.

It has not yet, perhaps, realised the dreams of those who have expected it to furnish a means of utilising the power of the Niagara Falls to light the towns and drive the mills of the Northern States, or of such smaller falls as those of the Clyde to light the City of Glasgow, and to work the steam-hammers of the ship-yard forges. It may not yet have been the means of storing up the power of the tides, of the river-floods, of the lightning-flash, or of the solar heat. Nevertheless, the record of its achievements which we have been able to detail, is sufficiently great to show how extremely rash it would be for any one to assign a limit to what it may possibly accomplish in the future. Indeed, nearly all the triumphs of science mentioned in Macaulay's eulogium of the Philosophy of Bacon may be claimed for electricity:—

"It has lengthened life; it has mitigated pain; it has extinguished diseases; it has given new securities to the mariner; it has furnished new arms to the warrior; it has guided the thunderbolt innocuously from heaven to earth; it has lighted up the night with the splendour of the day; it has extended the range of human vision; it has multiplied the power of the human muscles; it has accelerated motion; it has annihilated distance; it has facilitated intercourse, correspondence, all friendly offices, and all despatch of business; it has enabled man to descend to the depths of the sea, to penetrate securely into the noxious recesses of the earth, to traverse the land in cars which whirl along without horses. These are but a part of its fruits, and of its first-fruits. Its law is progress. A point which yesterday was invisible is its goal to-day, and will be its starting-post to-morrow."

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